



(22) Date de dépôt/Filing Date: 2010/10/19

(41) Mise à la disp. pub./Open to Public Insp.: 2011/05/06

(45) Date de délivrance/Issue Date: 2013/07/23

(30) Priorité/Priority: 2009/11/06 (US12/613,700)

(51) Cl.Int./Int.Cl. *G01V 8/02* (2006.01),  
*G01J 3/08* (2006.01), *G01J 3/10* (2006.01),  
*G01J 3/28* (2006.01), *E21B 49/00* (2006.01),  
*G02B 6/04* (2006.01)

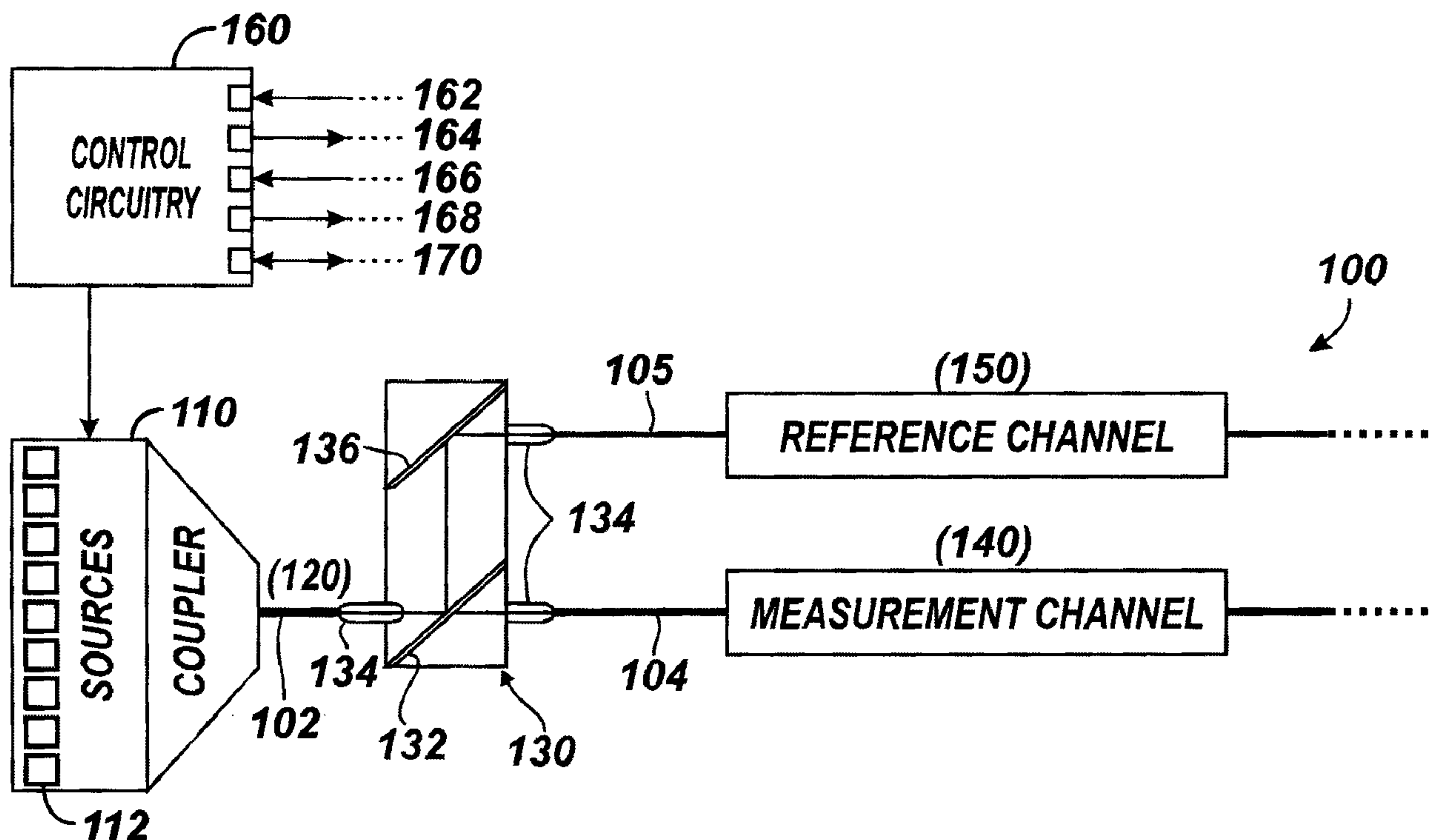
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(54) Titre : SOURCE A PLUSIEURS CANAUX POUR SPECTROSCOPIE AU FOND DE TROUS DE FORAGE

(54) Title: MULTI-CHANNEL SOURCE ASSEMBLY FOR DOWNHOLE SPECTROSCOPY



(57) Abrégé/Abstract:

A multi-channel source assembly for downhole spectroscopy has individual sources that generate optical signals across a spectral range of wavelengths. A combining assembly optically combines the generated signals into a combined signal and a routing assembly that splits the combined signal into a reference channel and a measurement channel. Control circuitry electrically coupled to the sources modulates each of the sources at unique or independent frequencies during operation.



1                   **“MULTI-CHANNEL SOURCE ASSEMBLY FOR DOWNHOLE**  
2                                           **SPECTROSCOPY”**

3  
4                                   FIELD OF THE INVENTION

5           Embodiments of the invention are related to sensors for use in testing  
6   downhole formations, analyzing fluids and performing other operations and more  
7   particularly to a multi-channel source assembly to provide optical signals for  
8   downhole spectroscopy and suitable for use in space-restricted, harsh wellbore  
9   conditions.

10                                   BACKGROUND

11           Downhole tools use various types of sensors to test a downhole formation,  
12   analyze fluids, and perform other operations.   Because the downhole  
13   environment has high temperatures, high pressures, harsh chemicals, and  
14   mechanical vibrations, the downhole tools must be mechanically designed to  
15   handle problems associated with such harsh conditions, and the downhole  
16   sensors must be able to operate with analytical accuracy and reliability. Added  
17   to these challenges, the downhole sensors must fit in the limited space available  
18   in the downhole environment, must be light weight and power efficient, and have  
19   a large dynamic range.

20           In the art, spectrophotometers, spectrometers, spectrofluorometers,  
21   refractive index analyzers, and similar devices have been used to analyze  
22   downhole fluids by measuring the fluid's spectral response. Each of these  
23   devices typically use some form of EM radiation to perform its function (*i.e.*, to  
24   analyze the fluid). In general, the wavelengths of the EM radiation can be in the  
25   x-ray, gamma, ultraviolet, visible, infrared or any combination of these ranges.

1 When the radiation is detected, the response can identify characteristics of the  
2 analyzed fluid, such as the type of fluid (e.g., oil, water, and/or gas), the level of  
3 filtrate contamination, the hydrocarbon composition (e.g., amount of methane  
4 (C1), ethane (C2), propane (C3), etc.), the gas-to-oil ratio (GOR), etc.  
5 Knowledge of these characteristics can then be employed to model the reservoir,  
6 plan production, and perform other tasks.

7 A number of optical devices have been developed in the art for spectral  
8 analysis. For example, a spectrometer disclosed in US Patent No. 6,075,595 is  
9 based on light emitting diodes (LEDs) and is capable of imaging into a single  
10 optical channel. See *also* Malinen et al., "LED-based NIR Spectrometer Module  
11 for Hand-Held and Process Analyser Applications," Sensors & Actuators B, vol.  
12 51, no. (1-3), pp. 220-226 (1998). In another example, a multi-wavelength  
13 photometer uses seven LEDs, 1-mm plastic optic fibers, a 7x2 coupler, and two  
14 photodiodes. See Hauser et al., "A Multi-wavelength Photometer Based on Light-  
15 Emitting Diodes," Talanta, vol. 42, no. 4, pp. 605-612 (1995). Still other small  
16 spectrometers also use LEDs. See Cantrell et al., "The SLIM Spectrometer,"  
17 Analytical Chemistry, vol. 75, no. 1, pp. 27-35 (2003); See *also* Yeh et al., "Low  
18 Cost LED Based Spectrometer," Journal of the Chinese Chemical Society, vol.  
19 53, pp. 1067-1072 (2006). None of these devices is suitable for use in a  
20 downhole environment due to the harsh temperature and pressure requirements  
21 in the borehole environment.

22 Other devices disclosed in the art can be used downhole. In US Patent  
23 No. 6,476,384 to Mullins et al., for example, a device has a broadband halogen

1 lamp source and has a mechanical chopper wheel driven by a motor. The lamp  
2 is imaged into an optical fiber bundle, and light from the bundle is directed to a  
3 photodiode used to synchronize the chopper wheel's motor. A calibration wheel  
4 driven by a rotary solenoid switch selects whether light from the bundle passes  
5 into a first path, a second path, or both. In the first path, light is directed to a light  
6 distributor forming part of a detector. In the second path, light is provided as  
7 input to a measurement cell and is afterward directed to the light distributor for  
8 the detector. The light distributor distributes the light received from the paths to a  
9 number of different channels with each channel having a lens, a bandpass filter,  
10 and a photodiode. While this device's broadband source does provide a number  
11 of spectral channels, the device must use a mechanical chopper, cannot perform  
12 synchronous detection, and requires a complex spectral detection system  
13 consisting of multiple photodiodes (*i.e.*, one per spectral channel).

14 In US Patent Publication No. 2007/0109537, Vannuffelen et al. discloses  
15 an alternative approach that utilizes mechanical choppers and motors.  
16 Unfortunately, this approach, by design, is apparently limited to conventional  
17 raster scanning (CRS) spectroscopy, which involves scanning a plurality of  
18 sources or measurement wavelengths in a sequential fashion using a fixed time  
19 per channel (*i.e.* source or wavelength). As a consequence, CRS prevents  
20 synchronous detection of all spectral channels. Moreover, the device requires  
21 reference and measurement signals to be de-convolved using a single detector.  
22 Because the signal convolution using a single mechanical chopper results in  
23 shared harmonics, the device uses dual mechanical chopper assemblies to

1 circumvent the complication of shared harmonics. Although this may simplify  
2 signal de-convolution, it adds further complexity to the devices and raises  
3 concerns relative to space, mechanical reliability, and accuracy.

4 Therefore, in light of the above, what is lacking in the art is a viable  
5 broadband multi-channel source for downhole spectral analysis that enables self  
6 referencing, low-power operation, synchronous detection, and S/N improvement  
7 using discrete modulation of individual spectral channels.

8 A number of optical devices have been developed in the art for spectral  
9 analysis. For example, small spectrometers use LEDs and detectors. See  
10 Cantrell et al., "The SLIM Spectrometer," *Analytical Chemistry*, vol. 75, no. 1, pp.  
11 27-35 (2003); See also Yeh et al., "Low Cost LED Based Spectrometer," *Journal*  
12 *of the Chinese Chemical Society*, vol. 53, pp. 1067-1072 (2006).

13 In another example, a spectrometer disclosed in US Patent No. 6,075,595  
14 uses light emitting diodes (LEDs) for light sources and uses a detector for  
15 detection. The spectrometer can image the LEDs into a single optical channel,  
16 and the detector obtains the radiation pulses related to each LED in turn. See  
17 also Malinen et al., "LED-based NIR Spectrometer Module for Hand-Held and  
18 Process Analyser Applications," *Sensors & Actuators B*, vol. 51, no. (1-3), pp.  
19 220-226 (1998). Thus, it appears that the spectrometer is not capable of  
20 synchronous detection.

21 In another example, a multi-wavelength photometer uses seven LEDs, 1-  
22 mm plastic optic fibers, a 7x2 coupler, and two photodiodes. See Hauser et al.,  
23 "A Multi-wavelength Photometer Based on Light-Emitting Diodes," *Talanta*, vol.

1 42, no. 4, pp. 605-612 (1995). The two photodiodes can apparently correct for  
2 drift and intensity differences. In addition, the LEDs are illuminated one at a time  
3 so that the photometer does not appear capable of synchronous detection.

4 None of the above-described devices is suitable for use in a downhole  
5 environment. Moreover, each of the devices only offers a limited number of  
6 spectral channels for output and detection, which adversely affects both spectral  
7 resolution and range in detection and further makes these devices unsuitable for  
8 downhole use.

9 In US Patent Nos. 7,336,356 and 7,379,180 to Vannuffelen et al., a device  
10 has a broadband source that may have a plurality of light sources. The device  
11 uses a rotating chopper wheel rotated by a motor to modulate the frequency of  
12 reference and measurement paths independently. For example, the  
13 measurement path has a first frequency and is split into two parts, and the  
14 reference path has a second frequency and is split into two parts. Each of these  
15 parts is then routed to multiple detection systems.

16 Another device for downhole analysis of fluids disclosed in US Patent  
17 Publication No. 2007/0013911 to DiFoggio et al. provides Wavelength  
18 Modulation Spectroscopy (WMS). The device uses a narrow light beam source  
19 and a tunable optical filter (TOF). In additional disclosures of US Patent Nos.  
20 7,280,214 and 7,362,422, both electrically tunable filters and mechanically (i.e.  
21 rotating) tunable filters are used for WMS. As purported, WMS eliminates the  
22 need for a second spectral reference channel. However, the devices have  
23 limited spectral range, which limits their use for downhole analysis of fluids.

1 Specifically, each filter, whether electrical or mechanical in nature, possesses a  
2 limited tunable spectral bandwidth. To increase spectral range, the device  
3 requires multiple narrow band sources and tunable filters, which is mechanically  
4 cumbersome for the downhole environment. In addition, the device uses a single  
5 channel detection system that prohibits synchronous detection because the  
6 tunable optical filters are actuated using a single motor assembly, which gives  
7 each spectral channel a common fundamental frequency. Thus, it appears that  
8 the device uses conventional raster scanning and is not capable of synchronous  
9 detection.

10 As disclosed in US Patent Publication No. 2008/0165356 to DiFoggio et  
11 al., another device has a laser diode array source containing a plurality of  
12 semiconductor light sources that enable conventional raster scanning (CRS) and  
13 Hadamard and synchronous Fast-Fourier Transform (FFT) scanning. However,  
14 the device lacks a way to dynamically scale the spectral response, and the  
15 device's sources lack a way for imaging a large number of spectral channels into  
16 a single spectral analyzer.

17 Therefore, in light of the above, what is lacking in the art is a downhole  
18 detection system that is amenable for use with a broadband multi-channel source  
19 for downhole spectral analysis and that enables self-referencing, low-power  
20 operation, synchronous detection, and S/N improvement using discreet  
21 modulation of individual spectral channels.

22

23



1           In one implementation, the routing assembly has one or more couplers  
2   optically coupled to each of the sources and has a router optically coupled to the  
3   couplers to split the combined signals into the reference and measurement  
4   channels. The couplers can be optical fibers--each having one of the sources  
5   imaged therein. Each of the fibers can then bundle together into a fiber bundle  
6   optically coupled to a router. Alternatively, the fibers can be fused with one  
7   another using a tree topology. In another alternative, the coupler can be a  
8   segmented mirror having the sources arranged thereabout. This segmented  
9   mirror can image optical signals from each of the sources to at least one fiber  
10   optic cable optically coupled to the router. In still another alternative, the  
11   couplers can be a series of filters disposed adjacent the sources that image at  
12   least a portion of the optical signals from each of the adjacent sources to the  
13   same fiber optical cable.

14           In one implementation, the routing assembly (also referred to as a router)  
15   has a splitter fractionally splitting the combined signal from the sources into the  
16   reference and measurement channels. Alternatively, the router can be an  
17   adaptive optical element or scanning optic that oscillates between two or more  
18   orientations. The scanning optic in the first orientation produces the reference  
19   channel, whereas the scanning optic in the second orientation produces the  
20   measurement channel. Although the scanning optic asynchronously images the  
21   reference and measurement channels, the scanning optic can provide an  
22   enhanced signal throughput, especially if it is run at a substantially lower  
23   frequency relative to the modulation of the individual optical channels.

1           In one implementation, the sources are spatially configured on an array,  
2   and the routing assembly can be a transmissive or reflective grating optically  
3   coupled to the spatially configured sources. The grating can combine the  
4   generated signals from the sources into a common optical beam that is then  
5   imaged using a router into a reference channel and a measurement channel.  
6   Alternatively, the reference channel can be picked off at the image point of the  
7   grating assembly using a second optical fiber for the reference channel.  
8   However, in a preferred embodiment, the measurement channel is imaged using  
9   the first order reflection of the grating, and the reference channel is imaged using  
10   the second order reflection of the grating, thereby removing the requirement of a  
11   router assembly and improving spectral efficiency of the source assembly.

12           In operation, the control circuitry controls the sources by electronically  
13   modulating the sources. In general, the control circuitry can operate all of the  
14   sources simultaneously, a subset of the sources simultaneously, or each source  
15   individually. For example, the control circuitry can operate the sources in a  
16   synchronous encoding mode in which each of two or more sources are operated  
17   simultaneously and modulated with a unique frequency to generate optical  
18   signals. Alternatively, the control circuitry can operate the sources in an  
19   asynchronous encoding mode in which each of two or more sources are  
20   operated in a serial fashion with only one source on at any point in time.  
21   Moreover, the sources can be operated in an asynchronous Hadamard  
22   Transform encoding mode in which a unique sequence of a subset of the

1 sources is operated in a cyclic fashion with only one subset of the sources in  
2 operation at a given point in time.

3 A multi-channel detector assembly can be used in a downhole tool to  
4 measure optical signals for downhole spectroscopy. The detector assembly has  
5 individual spectral detectors that measure optical signals across a spectral range  
6 of wavelengths. These detectors can be a single-element photodiode, a multi-  
7 element photodiode, an avalanche photodiode, a photomultiplier tube, a micro-  
8 channel plate, a bolometer, or a thermopile.

9 In particular, the assembly has a reference unit with at least one reference  
10 detector and has a measurement unit with at least one measurement detector. The  
11 reference unit is optically coupled to a reference channel of a source, and the at  
12 least one reference detector detects first spectral signals across a spectral range  
13 of wavelengths from the reference channel. The measurement unit is optically  
14 coupled to a measurement channel of the source, and the at least one  
15 measurement detector detects second spectral signals from the measurement  
16 channel after interaction with a fluid sample.

17 In one implementation, a plurality of reference detectors and  
18 measurement detectors can be used. For the reference detectors, a first router  
19 assembly partitions the reference channel into a plurality of first beams or  
20 spectral bands and routes each of the first beams to one of the reference  
21 detectors. Similarly, a second router assembly partitions the measurement  
22 channel into second beams or spectral bands for routing to each measurement  
23 detector. The routers can use one or more optical elements disposed in an

1 optical path of the channel to partition the channel into two or more beams or  
2 spectral bands. The optical elements used can be high-pass filters, low-pass  
3 filters, dichroic elements, or an adaptive optical element.

4       Communicatively coupled to the reference and measurement detectors,  
5 conversion circuitry converts the first and second spectral signals into reference  
6 signals and measurement signals, and control circuitry communicatively coupled  
7 to the conversion circuitry processes these signals. In processing the signals,  
8 the control circuitry deconvolves the signals based on the type of encoding used  
9 to encode the spectral signals when output by the source. In general, the  
10 encoding can be based on Fast Fourier Transform (FFT) encoding, Hadamard  
11 encoding, temporal encoding, spectral encoding, or other type of encoding.

12       Because the assembly utilizes a dedicated reference channel, the control  
13 circuitry can process the measurement and reference signals from these  
14 channels to improve the operation of the source and to improve the detection  
15 capabilities of the detector assembly. To improve operation of the source, for  
16 example, the control circuitry can be operatively coupled to the source and can  
17 control output of spectral signals from the source based at least on the  
18 processed reference signals. Because the reference channel is a direct  
19 measurement of the source, the control circuitry can interrogate the source for  
20 fluctuations and/or weakness so that the control circuitry can thereby directly  
21 control the source's amplitude based on the reference channel. The control  
22 circuitry can also temporally sync the output of the spectral signals of the source

1 with at least the first spectral signals detected by the reference detector and  
2 control the source and detection accordingly.

3 To improve detection, for example, the control circuitry can use the  
4 reference channel to dynamically scale any measurement channel. With this  
5 dynamic scaling, the control circuitry can account for fluctuations, drift, etc. in the  
6 source and can improve the signal levels in both channels. For example, the  
7 control circuitry can dynamically scale the measurement signal with the reference  
8 signal when processing the signals. The result of this scaling is a scaled  
9 measurement signal that already has real-time correction of variations in the  
10 measurement channel caused by disparate environmental responses, such as  
11 but not limited to temperature changes, drift in the source's operation, and drift in  
12 the detector assembly's electronics. In other words, the control circuitry scales  
13 the measurement channel with the reference channel so that the scaled  
14 measurement channel is essentially immune to disparate environmental  
15 responses.

16 In addition to these forms of control, the control circuitry can receive data  
17 of one or more environmental conditions from one or more external transducers.  
18 The control circuitry can then use the information from the external transducers  
19 as input to a scaling function or a lookup table employed to scale the processed  
20 measurement signal. This scaling can thereby account for spectral changes that  
21 would be caused by the environmental conditions detected by the transducers.

22 In configuring the source, the control circuitry can configure the modulated  
23 pulse train for illuminating the source by defining amplitude, start time, pulse

1 frequency, duty cycle, pulse shape, or other temporal characteristic for the  
2 modulated pulse train. This modulated pulse train can then be used by the  
3 source to generate the output of spectral signals. Thus, the control circuitry  
4 having configured the source knows the modulated pulse train used, and the  
5 control circuitry mathematically deconvolves the detected spectral signals from  
6 the reference and measurement channels based on the known modulated pulse  
7 train configuration parameters provided by the source sync signal of the control  
8 circuitry.

9       The deconvolution uses a series of mathematical steps involving but not  
10 limited to mean centering, inverting, summing, and dynamic scaling. For  
11 example, by mean centering values of the pulse train, inverting the mean  
12 centered pulse train at unique temporal locations, and summing the inverted  
13 pulse train values, the control circuitry can determine a summed pulsed train  
14 value that can be directly correlated with an amplitude of the spectral signal.  
15 Ultimately, this correlation allows spectroscopic analysis to determine  
16 characteristics of the fluid interacting with the measurement channel. In addition  
17 to this form of deconvolution, optical signal deconvolution can utilize FFT or  
18 Hadamard mathematical transformations, each requiring a set of operational  
19 parameters specified by the control circuitry.

20       The foregoing summary is not intended to summarize each potential  
21 embodiment or every aspect of the present disclosure.

22

1                    BRIEF DESCRIPTION OF THE DRAWINGS

2                    Fig. 1 illustrates a downhole tool having a measurement device for fluid  
3 analysis;

4                    Fig. 2A schematically illustrates a measurement device for fluid analysis  
5 having a multi-channel source assembly, reference and measurement channels,  
6 a sample unit, control circuitry, and a detector unit;

7                    Fig. 2B shows the general operation of the measurement device shown in  
8 Fig. 2A;

9                    Fig. 3A illustrates a first arrangement of a multi-channel source assembly  
10 having a multiple spectral sources and having a router assembly with a splitter  
11 and reflector;

12                   Fig. 3B illustrates a second arrangement of a multi-channel source  
13 assembly having multiple spectral sources and having an adaptive optical  
14 element;

15                   Figs. 4A-4B illustrate housing arrangements for the disclosed multi-  
16 channel source assembly;

17                   Fig. 5A illustrates a beam coupling assembly having individual sources  
18 and fibers;

19                   Fig. 5B illustrates an end-view of a fiber bundle for the beam coupling  
20 assembly of Fig. 5A;

21                   Figs. 6A-6B illustrate a fiber coupling between an individual source and an  
22 optical channel;

1           Fig. 7 illustrates how the beam coupling assembly of Fig. 5A-5B can be  
2 imaged into a single optical channel;

3           Fig. 8 illustrates another beam coupling assembly having a tree topology;

4           Fig. 9 illustrates another beam coupling assembly having a segmented  
5 mirror;

6           Figs. 10A-10B illustrate bulk coupling assemblies having a series of  
7 source and filters imaging optical signals into a single optical channel;

8           Figs. 11A-11B illustrate additional bulk coupling assemblies having a non-  
9 linear arrangement of sources and filters imaging optical signals into a single  
10 optical channel;

11          Figs. 12A-12B illustrate bulk coupling assemblies utilizing optical  
12 microbenches;

13          Figs. 13A-13D illustrate beam coupling assemblies that use an array of  
14 sources and a grating;

15          Figs. 14A-14B illustrate a routing assembly having a splitter/reflector;

16          Fig. 15A illustrates a side view of a measurement device having a multi-  
17 channel source assembly and a detector unit;

18          Fig. 15B diagrammatically illustrates arrangements for the source  
19 assembly and the detector units of the device in Fig. 15A;

20          Fig. 16 schematically illustrates control circuitry for the disclosed multi-  
21 channel source assembly;

22          Fig. 17A schematically illustrates a measurement device for fluid analysis  
23 having a source assembly, a sample unit, and a detector assembly;

1            Fig. 17B shows the general operation of the measurement device shown  
2    in Fig. 2A;

3            Fig. 18 schematically illustrates the detector assembly having single  
4    detector units;

5            Figs. 19A-19B illustrate exploded views of a fiber coupling to a detector for  
6    the single arrangement of Fig. 18;

7            Fig. 20 schematically illustrates the detector assembly having dual  
8    detector reference and measurement units;

9            Figs. 21A-21C illustrate fiber-based routers for the dual detector units of  
10   Fig. 20;

11           Fig. 22 shows an exemplary lens optic for the routers of Fig. 21A-21C;

12           Fig. 23 shows a router for the dual detector unit having the lens optic of  
13   Fig. 22 and having a reflector;

14           Figs. 24A-24B illustrate additional routers for multi-detector units;

15           Fig. 25 schematically illustrates control circuitry for the disclosed detector  
16   assembly having a dual detector reference and measurement unit arrangement;

17           Fig. 26 illustrates a side view of a measurement device having a multi-  
18   channel source assembly and a detector unit;

19           Fig. 27 diagrammatically illustrates arrangements for the source assembly  
20   and the detector units of the device in Fig. 11;

21           Fig. 28 shows a process for performing a fixed frequency analysis mode of  
22   operation; and

1 Figs. 29A-29C show examples of signals during processing under the  
2 mode of Fig. 26.

### 3 4 DETAILED DESCRIPTION

#### 5 6 A. Downhole Tool Having Measurement Device For Fluid Analysis

7  
8 A downhole tool 10 in Fig. 1 has a measurement device 30 for in-situ  
9 sampling and analysis of fluids in a wellbore. A conveyance apparatus 26 at the  
10 surface deploys the tool 10 downhole using a tubular, a cable, a wireline, or  
11 similar component 27. As shown in Fig. 1, the tool 10 can be a formation tester  
12 such as disclosed in U.S. Patent Publication No. 2008/0173083, filed January 24,  
13 2007. However, the measurement device 30 can be deployed in any suitable  
14 tool used for wireline formation testing, production logging, Logging While  
15 Drilling/Measurement While Drilling (LWD/MWD), or other operations.

#### 16 17 1. Downhole Tool

18 As shown in Fig. 1, the formation tester tool 10 has dual fluid flow lines  
19 24/25 that extend through sections of the tool 10 and that are functionally  
20 configurable. However, other types of formation tester tools could also be used,  
21 such as those having a single flow line. In operation, a probe 12 having an  
22 intake port draws fluid into the tool 10. To isolate the formation fluid samples  
23 from contaminants in the annulus, the tool 10 can use isolation elements, such  
24 as packers 11 or other devices, to isolate a region of the formation.

1           A pump 20 then pumps collected fluid from the probe 12 into the tool 10  
2   via the flow lines 24/25. The fluid, which can contain hydrocarbon components  
3   (solid, liquid, and/or gas) as well as drilling mud filtrate or other contaminants,  
4   flows through the tool 10, and various instruments and sensors in the tool 10  
5   analyze the fluid. For example, a measurement section 14 can have sensors  
6   that measure various physical parameters (*i.e.*, pressure, temperature, etc.) of  
7   the fluid, and the measurement device 30 in the fluid analysis section 16 can  
8   determine physical and chemical properties of oil, water, and gas constituents of  
9   the fluid downhole. Eventually, fluid directed via the flow lines 24/25 can either  
10   be purged to the annulus or can be directed to the sample carrier 18 where the  
11   samples can be retained for additional analysis at the surface.

12           Additional components 22 of the tool 10 can hydraulically operate valves  
13   and other elements within the tool 10, can provide control and power to various  
14   electronics, and can communicate data via wireline or fluid telemetry to the  
15   surface. Uphole, surface equipment 28 can have a surface telemetry unit (not  
16   shown) to communicate with the downhole tool's telemetry components. The  
17   surface equipment 28 can also have a surface processor (not shown) that  
18   performs additional processing of the data measured by the tool 10.

19

20           B. Measurement device For Downhole Fluid Analysis

21           As noted above, the fluid analysis section 16 uses the measurement  
22   device 30 for downhole fluid analysis. Depending on the configuration and types  
23   of sources and detectors used and their orientation relative to a sample, the

1 measurement device 30 can operate as a photometric analyzer, reflectometer,  
2 spectroscope, spectrophotometer, spectrometer, or the like. For example, the  
3 measurement device 30 can operate as a multi-channel photometric analyzer in  
4 which discrete wavelengths are interrogated over a given measurement range. In  
5 common usage, such a multi-channel photometric analyzer can be referred to as  
6 a spectrometer. Thus, the measurement device 30 can use various spectral  
7 channels to perform spectroscopic analysis of downhole fluid passing relative to  
8 it as the fluid is pumped through the tool 10 (Fig. 1). As such, the spectroscopic  
9 analysis discussed herein can include, but may not be limited to, analysis of  
10 transmission, absorbance, or both, and can apply chemometrics, derivative  
11 spectroscopy, and other techniques known in the art. Details of how a  
12 spectroscope can be implemented in a downhole tool are disclosed in U.S.  
13 Patent No. 7,508,506.

14 As schematically shown in Fig. 2A, the measurement device 30 has a  
15 multi-channel source assembly 40, a sample unit 70, and a detector unit 80. The  
16 source assembly 40 has a plurality of sources 42, a coupler 44, a router 46, and  
17 control circuitry 48. When operated, the source assembly 40 generates optical  
18 signals with the sources 42, and the coupler 44 combines the generated signals  
19 from the sources 42 and couples the combined signal to the router 46. In turn,  
20 the router 46 routes the combined signal into a reference channel 60 and into a  
21 measurement channel 50 for interrogating a sample.

22 The downhole source assembly 40 preferably meets particular  
23 characteristics. Preferably, the source assembly 40 offers a broadband source of

1 optical signals (EM radiation), but contains a number of independently operable  
2 channels (*i.e.*, wavelength regions) that are spectrally aligned to cover a broad  
3 spectral range. Therefore, the individual sources 42 generating the optical  
4 signals preferably have a discrete wavelength or a distribution of wavelengths  
5 across a spectrum of wavelengths, and the sources 42 preferably provide unique  
6 optical channels (*i.e.*, wavelength regions) of interest that are amenable to  
7 various applications and wavelengths of interest in a downhole environment.

8 In general, the combination of sources 42 can provide a continuous  
9 spectral distribution over a broad spectral range. Alternatively, the sources 42  
10 can cover a broad spectral range having a non-continuous spectral distribution of  
11 two or more spectrally continuous regions interposed by at least one spectrally  
12 dark region. As discussed below and depending on the implementation, each  
13 source 42 is preferably capable of independent modulation at a unique or  
14 independent frequency, which enables synchronous detection. In addition, one  
15 or more of the sources 42 may be spectrally filtered and spatially shaped using a  
16 series of optical elements. Finally, the source assembly 40 preferably enables  
17 continuous signal scaling using in-situ reference and dark correction and is  
18 preferably energy efficient and long lived. In addition, the source assembly 40  
19 preferably enables dynamic scaling by using its integrated reference channel and  
20 dynamic dark correction and using its ability to turn all sources 42 off or block all  
21 output in the measurement and reference channels on command. Finally, the  
22 source assembly 40 is preferably energy efficient and long lived.

1           To help meet the above characteristics, the sources 42 in the assembly 40  
2   preferably include multi-channel solid state sources, including but not limited to  
3   light emitting diodes (LED), super-luminescent light emitting diodes (SLED), and  
4   laser diodes (LD), where each of the individual sources 42 are coupled using a  
5   fiber bundle, a fiber coupler such as a star coupler, a bulk spectral coupler, or  
6   some other coupler 44 as disclosed herein.

7           More detailed operation of the measurement device 30 is discussed  
8   concurrently with reference to Fig. 2B. The control circuitry 48 modulates the  
9   assembly's individual sources 42 at unique or independent frequencies and  
10   encodes the generated signals so that Conventional Raster Scanning (CRS),  
11   Fourier Transform (FT), or other methods known to those skilled in the art can be  
12   used for spectroscopic analysis (Block 90). The coupler 44 optically couples to  
13   the generated signals of each of the sources 42 and combines the generated  
14   signals into an input channel (Block 91). Optically coupled to this input channel,  
15   the router 46 routes the input channel into a measurement channel 50 and a  
16   reference channel 60 (Block 92). Throughout this disclosure, these channels  
17   50/60 or light paths are referred to as a "measurement channel" and a "reference  
18   channel" to indicate that the measurement channel 50 interrogates a sample with  
19   EM radiation while the reference channel 60 is used for continuous referencing.  
20   Although one measurement channel 50 is shown along with one reference  
21   channel 60, it will be appreciated that multiple measurements channels 50 can  
22   be provided for the same reference channel 60. Therefore, the device 30 can

1 have several measurement channels 50 along with sample assemblies 70 and  
2 detector units 80 for separate analysis.

3 For the measurement channel 50, the encoded signals interact with a  
4 sample fluid via the sample unit 70 (Block 93). For its part, the sample unit 70  
5 can use different designs, including, but not limited to, a sample cell, a  
6 reflectance accessory, a transmittance accessory, a fluorescence accessory, an  
7 Attenuated Total Reflectance (ATR) accessory, an extractive flow cell, or any  
8 other sampling or monitoring device known to those skilled in the art. After  
9 interaction with the sample, the detector unit 80 detects the measurement  
10 channel 50 for analysis (Block 94). Detectors in the unit 80 can cover the  
11 required spectral bandwidth provided and can use any of the various available  
12 detector materials (*i.e.*, Si, InGaAs, PbS, PbSe, MCT, etc.) and any of the  
13 various available configurations (*i.e.* photodiodes (PD), avalanche photodiodes  
14 (APD), photomultiplier tubes (PMT), Multi-Channel Plates (MCP), *etc.*).

15 Concurrent with the interrogation of the measurement channel 50, the  
16 reference channel 60 is also interrogated (Block 95). The control circuitry 48  
17 receives detected signals from the detector unit 80, containing both the  
18 measurement and reference detectors. Then, the control circuitry 48 correlates  
19 the received signals and continuously scales the measurement channel 50's  
20 signal by the reference channel 60's signal to account for downhole  
21 environmental conditions, drift, or the like (Block 96). Once the received signals  
22 are scaled and decoded, the resulting spectral data can be used to determine  
23 chemical and/or physical properties of the sample fluid. This can be performed

1 by the control circuitry 48 or by some other controller. Ultimately, as referenced  
2 above, the measurement device 30 of Fig. 1 can transmit spectral data to a  
3 processing system (not shown) located on the tool 10 or at the surface  
4 equipment 28.

5

### 6 C. Downhole Multi-Spectral Source Assembly

7 With an understanding of the measurement device 30 and the downhole  
8 tool 10 in which it can be deployed, discussion now turns to Figs. 3A-3B showing  
9 different arrangements of a multi-channel source assembly 100 for downhole  
10 spectroscopy according to certain teachings of the present disclosure.

11

#### 12 1. First Arrangement Having Router with Splitter and Reflector

13 In a first arrangement shown in Fig. 3A, the multi-channel source  
14 assembly 100 has a source-coupler unit 110, a router assembly 130, and control  
15 circuitry 160. As discussed briefly above and in more detail later, the source-  
16 coupler unit 110 has a plurality of sources 112. The control circuitry 160 can  
17 electrically modulates each individual source 112 at a unique or independent  
18 frequency, and the unit 110 optically couples the generated signals of each  
19 individual source 112 to an input channel 120, which may be carried by an  
20 individual fiber, a fiber bundle, or other device 102 as disclosed herein.

21 At the router assembly 130, an optic 134, such as a collimator, collimates  
22 the input channel 120, and a fractional beam splitter 132 then creates fractional  
23 beam intensity along separate optical paths to produce two separate channels —  
24 a measurement channel 140 and a reference channel 150. To achieve the

1 highest possible signal-to-noise ratio in the measurement channel 140, only a  
2 small portion (*i.e.*, 5-10%) of the input channel 120 is routed into the reference  
3 channel 150. The remaining percentage is routed into the measurement channel  
4 140. Overall, the use of a reference channel 150 improves the accuracy and  
5 precision of the resulting measurement.

6 As shown, the router 130 creates a first optical path constituting a first  
7 fraction or majority of the input channel 120. This first optical path passes  
8 through an optic 134 to an optical path 104 for the measurement channel 140.  
9 As shown, this path 104 can use a fiber or can pass through free space. The  
10 router 130 also creates a second optical path constituting a second fraction or  
11 minority of the input channel 120. In one implementation, the measurement  
12 channel 140 constitutes 90% of the input channel 120, while the reference  
13 channel 150 constitutes 10% of the input channel 120, although other  
14 percentages could be used in other implementations.

15 The second optical path from the splitter 132 passes to a reflector 136,  
16 which can be a mirror, a prism, or other comparable device. The reflector 136  
17 directs the reference channel 150 through another optic 134 and into an optical  
18 path 105 for the reference channel 150. Again, this path 105 can use a fiber or  
19 can pass through free space. In this way, the reflector 136 enables the optical  
20 paths 104/105 carrying the two channels 140/150 to be positioned adjacent and  
21 parallel to one another to conserve space in the source assembly 100 used  
22 downhole.

1           After splitting, the measurement channel 140 can be used to analyze fluid  
2   using sample and detector units (not shown), for example, or for other purposes.  
3   For its part, the reference channel 150 can be used to provide optical feedback  
4   from the detection unit (not shown) to the control circuitry 160 for controlling the  
5   sources 112, to dynamically scale the optical signal of the measurement channel  
6   140, and to perform other functions as discussed in more detail below.

7           As shown in Figs. 3A and 3B, the control circuitry 160 has a number of  
8   inputs and outputs that can be used for various purposes discussed later. (See  
9   e.g., Fig. 16). Briefly, the control circuitry 160 has a digital/trigger input 162,  
10   digital/trigger output 164, and a communications interface 170 that can be used  
11   for external control of the control circuitry 160. Also, an analog input 166 can be  
12   used for an automated control scheme and can receive analog measurement  
13   signals from separate detectors. Finally, either the analog output 168 or  
14   communications interface 170 can be used for messaging, such as sending  
15   status messages concerning the health of the source assembly 100. For  
16   example, the control circuitry 160 can use the inputs and outputs to interact with  
17   external control circuitry (not shown) of a detection system and to dynamically  
18   adjust the source assembly's operation based on that interaction.

19

## 20                   2. Second Arrangement Having Router with Scanning Optic

21           In a second arrangement shown in Fig. 3B, the source assembly 100  
22   again has source-coupler unit 110, router assembly 130, and control circuitry  
23   160. Generating the input channel 120 can follow the same course as discussed

1 previously. In contrast to the previous arrangement, the router assembly 130  
2 uses an adaptive optical element or scanning optic 135 (as opposed to the  
3 fractional beam splitter 132 as in Fig. 3A) to route the input channel 120 into  
4 separate channels 140/150. The scanning optic 135 can be a scanning mirror,  
5 Micro-Electro-Mechanical System (MEMS) scanning mirror. Details of using a  
6 scanning optic are disclosed in U.S. Patent No. 7,508,506.

7 In use, an optical assembly 134 at the router assembly 130 collimates the  
8 input channel 120 generated by the source-coupler unit 110. Then, the scanning  
9 optic 135 routes the input channel 120 by serially directing all of the input  
10 channel 120 at two optical assemblies 134 relative to the scanning optic 135.  
11 Furthermore, the input optical assemblies 134 can be used to improve the beam  
12 shape, dispersion, or intensity using various available optics not shown for  
13 simplicity. In addition, the scanning optic 135's orientation is controlled via a  
14 controller — either independent from or integrated into the control circuitry 160.

15 In one orientation, for example, the scanning optic 135 directs all of the  
16 input channel 120 to an optic 134 and along light path 104 for the measurement  
17 channel 140, which can interact with sample and detector units (not shown).  
18 Once oscillated or rotated, the scanning optic 135 then directs all of the input  
19 channel 120 to an optic 134 and along light path 105 for the reference channel  
20 150, which can be interrogated by a detector unit (not shown). As should be  
21 apparent, because the switch between the two channels 140/150 having the  
22 spectrum of interest can occur relatively quickly and repeatedly, the reference  
23 channel 150 can be used to normalize the output of the measurement channel

1 140 to provide for a dynamically scaled reading. As implemented, the scanning  
2 optic 135 asynchronously images the total intensity of the input channel 120 to  
3 the reference and measurement channels 140/150, as opposed to fractionally  
4 splitting the intensity between measurement and reference channels 150/140 in  
5 Figure 3A. Consequently, the scanning optic 135 can provide an enhanced  
6 signal-to-noise ratio, especially if it is run at a substantially lower frequency  
7 relative to the modulation of the individual sources 112. In addition, multiple  
8 measurements channels (not shown) could be utilized with this implementation.

9 In Figs. 3A-3B, two arrangements for the source assembly 100 have been  
10 shown. It will be appreciated with the benefit of the present disclosure that other  
11 arrangements are possible and that components from one of the disclosed  
12 arrangements can be exchanged or combined with those of another arrangement  
13 disclosed herein.

14

#### 15 D. Housing Arrangements For Multi-Channel Source Assembly

16 Because the source assembly 100 is used downhole, housing its  
17 components can be constrained by the available tool space and the downhole  
18 environmental specifications. Ideally, components of the source assembly 100  
19 have a housing that is amenable to downhole deployment and that can fit into the  
20 tight downhole space required in a downhole tool. Therefore, the source  
21 assembly 100 is preferably constructed as a discrete modular unit that can be  
22 incorporated or connected to other modular units for sampling and detection in a  
23 downhole tool.

1 Figs. 4A-4B illustrate housing arrangements for the source assembly 100  
2 disclosed herein. In one example, the source assembly 100 in Fig. 4A has a  
3 housing 180 that contains a source-coupler unit 110, a router assembly 130, and  
4 control circuitry 160 similar to those discussed previously. Externally, the  
5 housing 180 has at least one electrical connector 182 for coupling the internal  
6 components to power, environmental sensors (not shown), communications, and  
7 external control elements (not shown). In addition, the housing 180 has at least  
8 two optical connectors 184/185 that couple the housing 180 to other units. For  
9 example, one optical connector 184 can carry the measurement channel 140 to  
10 the sample unit and the detection unit (not shown), and the other optical  
11 connector 185 can carry the reference channel 150 to the detector unit (not  
12 shown).

13 In another example, the source assembly 100 in Fig. 4B has a housing  
14 180 again containing a source-coupler unit 110 and a router assembly 130.  
15 Externally, the housing 180 has at least one electrical connector 182 for coupling  
16 the internal components to power, environmental sensors (not shown), and  
17 external control elements (not shown) and has one optical connector 184 that  
18 couples the housing 180 to the sample unit and the detection unit (not shown) for  
19 the measurement channel 140. For compactness, optical fibers or optical light  
20 paths 104/105 for the channels 140/150 are arranged parallel to one another in  
21 the housing 180. To do this, the router assembly 130 has a splitter 132 and a  
22 reflector 136 that splits the input channel 120 into the measurement channel 140  
23 for fiber or optical light path 104 and into the reference channel 150 for fiber or

1 optical light path 105. (Details of such a router having combined splitter and  
2 reflector are illustrated in Figs. 14A-14B).

3 To remain small and rugged, the housings 180 and components  
4 discussed above are preferably kept within various size constraints. To  
5 withstand use downhole, the housings 180 for the assembly 100 also preferably  
6 meet shock and vibration requirements for the downhole environment.

7 Although the housing arrangements in Figs. 4A-4B have been described  
8 using only some of the components from the arrangements in Figs. 3A-3B, it will  
9 be appreciated that additional housing arrangements are possible using other  
10 components of the source assembly 100 disclosed herein.

11

## 12 E. Multi-Source Coupler Assemblies

13 As discussed previously in Figs. 3A-3B, the source assembly 100 uses a  
14 source-coupler unit 110 that generates optical signals with a plurality of individual  
15 sources 112 and combines the optical signals together into an input channel 120.  
16 Figs. 5A through 12B below disclose a number of combinations of sources and  
17 couplers that can be used for the source assembly 100.

18

### 19 1. Individual Sources and Couplers

20 In Fig. 5A, a source-coupler unit 200 has individual sources 210 and  
21 optical couplers 220. The individual sources 210, which can be electronic  
22 sources such as LEDs or the like, can be spectrally convolved or individually  
23 selected so their generated light can be used for spectroscopy or other analysis.  
24 For example, the control circuitry (160; Figs. 3A-3B) can illuminate the sources

1 210 using raster scanning, frequency modulation, or other techniques discussed  
2 herein.

3 Generated signals from each source 210 are optically coupled into its  
4 individual optical coupler 220, which each have one end optically coupled to one  
5 of the sources 210. As shown, each of these couplers 220 can be an optical  
6 fiber, although other individual optical couplers can be used, including optical  
7 waveguides, light pipes, mirrored conduits, or the like. Each of these individual  
8 fibers 220 then bundle together with one another to form a fiber bundle 230.  
9 Eventually, the end of the fiber bundle 230 can optically couple to a router  
10 assembly (130; Figs. 3A-3B) or can be imaged into a single fiber (See Figs. 7 &  
11 9) for coupling to the router assembly. As an alternative to the use of individual  
12 fibers 220, bulk optical or micro optical, free-space types of couplings can be  
13 used for the source assembly. Details of one such arrangement are disclosed  
14 herein.

15 Fig. 5B illustrates an end-view of the fiber bundle 230 composed of the  
16 individual fibers 220. As shown, the bundle 230 is a close-packed arrangement  
17 of the fibers 220. Each fiber 220 can be a stripped 100- $\mu\text{m}$  core/110- $\mu\text{m}$  clad  
18 fiber having a numerical aperture (NA) of 0.22. In this way, the bundle 230 of  
19 fibers 220 can have an approximate diameter of 700-microns and can behave  
20 like a 700-micron diameter point source for coupling to the router (130; Figs. 3A-  
21 3B) or to a single fiber (See Figs. 7 & 9).

22 Various optical elements may be used to image the generated light from  
23 the sources 210 to its corresponding fiber or light path 220, and some of the

1 sources 210 may or may not require an optical filter. Figs. 6A-6B show a  
2 representative optical coupling between a source 210 to an optical fiber or light  
3 path 220; however, those skilled in the art will recognize that alternative coupling  
4 methods could be used for this purpose.

5 As shown in Fig. 6A, generated light from the source 210 (shown having  
6 an LED die 212) is individually collimated and focused onto the fiber 220's end  
7 face. As shown, a collimating lens 214, a filter 216, and a coupling lens 218 are  
8 positioned between the source's die 212 and the optical fiber 220. The lenses  
9 214 and 218 have a region between them through which collimated light can  
10 pass through the filter 216. Positioned in this region, the filter 216 may require a  
11 relatively small range of angles in order to function correctly. If the LED source  
12 210 does not require filtering, a single lens may instead be used between the  
13 LED source 210 and the fiber 220.

14 As shown in Fig. 6B, the source 210 can have a TO-46 header, and a  
15 collar 215 can house the collimating lens 214, filter 216, and coupling lens 218 in  
16 fixed distances relative to the source 210's header. A sleeve 224 and a fiber  
17 ferrule 222 connect from the collar 215 to the optical fiber 220, which can be  
18 either a multimode or single mode fiber optic cable. In one arrangement, the  
19 multimode fiber optic cable employed has a 100-micron core diameter.

20 The filter 216 is a wavelength selection filter (*i.e.*, a bandpass filter).  
21 Preferably, the filter 216 is a hard-coated metal oxide bandpass filter compatible  
22 with downhole conditions. When used, the optical filter 216 reduces the adverse  
23 effects caused by the source's spectral characteristics (*i.e.*, center wavelength

1 and spectral bandpass) changing with temperature downhole. Although the  
2 optical filter 216 still changes center wavelength and bandpass, it may do so to a  
3 significantly lesser extent than the source 210 itself. Therefore, in some  
4 implementations, use of the filter 216 may be preferred.

5 As shown in Fig. 7 and noted previously, individual sources 210  
6 separately couple to optical fibers 220 that are formed into a fiber bundle 230 as  
7 with Figs. 5A-5B. As shown here, this bundle 230 optically couples to an optic  
8 lens 245 that images the generated signals into an input fiber 240 that can carry  
9 the signal to a router (130; Figs. 3A-3B), as discussed previously.

10 In an alternative shown in Fig. 8, individual sources 210 are each imaged  
11 into its own optical fiber 220, which can be done in a similar fashion described  
12 previously. Each optical fiber 220 is then fused with another source's fiber 220  
13 using a coupling member 235 that combines the input signal from fused fibers  
14 220 into an output signal for an output fiber 220. Then, the multiple sources 210  
15 and fibers 220 are combined in a tree or star topology 200, and the generated  
16 signals are subsequently combined into a common optical beam carried by an  
17 input fiber 240 to a router (130; Figs. 3A-3B), as discussed previously.

18

## 19 2. Individual Sources and Segmented Mirror

20 In Fig. 9, another source-coupler unit 220 for the disclosed source  
21 assembly has a segmented mirror 250. In this arrangement, the individual  
22 sources 210 are arranged in a circular or ring configuration — only a portion of  
23 which is shown. The segmented mirror 250 surrounded by these sources 210

1 images their light to the end of an input fiber 240, which can be a single, large-  
 2 core fiber optic cable or a fiber bundle, as well as a free space optical channel.  
 3 In turn, the input fiber 240 can convey the input channel to a router (130; Figs.  
 4 3A-3B), as discussed previously.

5

### 6 3. Individual Sources and Bulk Optical Combiners

7 In Figs. 10A-10B, source-coupler units 200 for the disclosed source  
 8 assembly have individual sources 210 imaged in a bulk arrangement into an  
 9 input fiber or light path 240. In Fig. 10A, for example, the unit 200 has a series of  
 10 low pass filters 260 that combine generated signals from the individual sources  
 11 210 into a common optical beam. At the end of the filters 260, an optic lens 262  
 12 images the common beam into the input fiber or light path 240. As shown,  
 13 bandpass filters 216 may be used between the sources 210 and the series of low  
 14 pass filters 260. Because low pass filters 260 are used, the various source/filter  
 15 combinations increase in wavelength ( $\lambda_0 - \lambda_7$ ) as they are positioned closer to the  
 16 input fiber 240 into which the common beam is imaged.

17 The sources 210 and filters 216/260 can be arranged at acute angles (as  
 18 in Fig. 10A) or arranged perpendicularly (as in Fig. 10B). In addition, the unit 200  
 19 in Fig. 10B has a series of high pass filters 264 (as opposed to low pass filters)  
 20 that combine light from the individual sources 210 into the common optical beam.  
 21 For this arrangement, the various source/filter combinations decrease in  
 22 wavelength ( $\lambda_7 - \lambda_0$ ) as they are positioned closer to the input fiber 240 into which  
 23 the common beam is imaged.

1           In addition to the above arrangements, Figs. 11A-11B show additional  
2 bulk arrangements of individual sources 210 and filters 266. Here, the sources  
3 210 are arranged in non-linear clusters and use filters 266 to direct and combine  
4 the wavelengths of interest from the sources 210. Ultimately, the optical signals  
5 are directed to a lens 262 that images the combined signal into the input fiber  
6 240. These configurations minimize the distance between the sources 210 and  
7 the input fiber or light path 240, thereby minimizing optical losses.

8

9                           4. Bulk Optical Couplers having Microbenches

10           Additional bulk optical couplers used for the source assembly 100 can use  
11 microbenches. As shown in a source-coupler unit 300 in Fig. 12A, various  
12 sources 310 position in patterns formed in the microbench 302. These patterns  
13 can be etched or micromached in the bench 302 using known techniques. A  
14 series of mirrors 312 are disposed in slots in the bench 302. Generated signals  
15 from the sources 310 are imaged onto the mirrors 312 that in turn reflect the  
16 signals to an optic lens 314. In turn, the lens 314 images the combined beam  
17 into a fiber, a fiber bundle, or light path 330 that carries the input channel to a  
18 router assembly (130; Figs. 3A-3B), as discussed previously.

19           A similar arrangement in Fig. 12B has input fibers 320 that carry  
20 generated signals from individual sources 310 to optic lenses 316. In turn, the  
21 lenses 316 image the signals onto the mirrors 312, and an optic lens 314  
22 receives signals from the mirrors 312 and images the combined beam into the  
23 fiber or bundle 330. As will be appreciated, the microbench 302 allows the

1 elements to be precisely aligned during manufacture and closely housed, which  
2 is advantageous for downhole use.

3

#### 4 5. Individual Sources and Grating Couplers

5 In Fig. 13A, a source-coupler unit 400 for the disclosed source assembly  
6 uses an array 420 of individual sources 410, a grating 430, and a controller 460,  
7 which can be part of the source assembly's control circuitry (160; Figs. 2A-2B).  
8 As shown, the individual sources 410, which can be LEDs or the like, are  
9 spatially configured on the array 420. The sources 410 generate optical signals  
10 in different spectral bands and can be activated in a number of patterns to  
11 encode the generated signals. In particular, the sources 410 can be arranged in  
12 off-set rows of a number of columns with the wavelength assigned for a particular  
13 source 410 depending on its location in the array 420. For example, sources 410  
14 may be arranged with increasing wavelengths along the axis of the array 420.

15 Controller 460 coupled to the array 420 can have a microprocessor 462, a  
16 pattern generator 464, and an array driver 466 to encode the illuminations of the  
17 sources 410. During use, the controller 460 selectively illuminates the sources  
18 410 to encode their generated optical signals in a desired pattern. Depending on  
19 the implementation, the illumination pattern may require that either a Hadamard  
20 transform, a Fourier transform, or other method be used to deconvolve the  
21 optical signals received at the detection assembly (not shown).

22 The reflective grating 430, which can be concave with its reflective focal  
23 surface incorporating fine rulings, reflects and diffracts the generated signals

1 from the sources 410 and directs the reflected beam 431 to a lens 435. In turn,  
2 the lens 435 images the beam 431 into a common input beam (120) that is  
3 directed to a router 130 similar to that discussed previously. The splitter 132 in  
4 the router 130 then partitions the input beam (120) into the measurement  
5 channel (140) and the reference channel (150) for use according to the purposes  
6 disclosed herein.

7 As an alternative to the router assembly 130, the source-coupler unit 400  
8 can instead use a combiner 440 shown in Fig. 13B to produce the measurement  
9 and reference channels (140/150) from the grating's reflected beam 431. The  
10 combiner 440 has a slit 442 disposed relative to two optical fibers 444/445. The  
11 reflected beam 431 from the grating (430) is directed to the combiner 440, where  
12 the slit 442 images the beam 431 to the spatially registered fibers 444/445. The  
13 first fiber 444 is for the measurement channel (140), while the second fiber 445 is  
14 for the reference channel (150). As shown, the measurement channel's fiber 444  
15 can be larger than the reference channel's fiber 445 so that a higher fraction of  
16 the common beam is imaged onto it. However, the spatially registered fibers  
17 444/445 can be of comparable size depending on the implementation.

18 In Fig. 13C, the source-coupler unit 400 again uses the array 420 of  
19 individual sources 410, the reflective grating 430, and the controller 460  
20 operating as described above. However, rather than using a router 130 (Fig.  
21 13A) or combiner 440 (Fig. 13B), the reflective grating 430 reflects a first order  
22 reflected beam 432 to a first lens 433 and reflects a second order reflected beam  
23 436 to a second lens 437. The first lens 433 images the first order beam 432,

1 which is stronger, into the measurement channel (140), while the second lens  
2 437 images the second order beam 436 into the reference channel (150). By  
3 using the first and second order reflections from the grating 430, the unit 400 can  
4 avoid using a beam splitter or other router devices, which can improve the  
5 spectral efficiency of the unit 400.

6 As an alternative to the reflective grating 430, the unit 400 in Fig. 13D  
7 uses a transmissive grating 450. Here, the sources 410 are arranged so that a  
8 common input beam (120) can be formed using the transmissive grating 450 and  
9 a lens 455. The array 420 of individual sources 410 and the controller 460 can  
10 operate the same as described previously, and the input beam (120) can be  
11 carried to a router (not shown). In general, the substrate of the gratings 430/450  
12 can be composed of metal, glass, silicon carbide, ceramic, quartz, sapphire, or  
13 the like. The materials specified are amenable to high temperature applications.

14

#### 15 F. Router Having Splitter and Reflector

16 In Fig. 14A, a router 500 (discussed briefly in Fig. 4B) for the disclosed  
17 source assembly has an integrated splitter 520 and reflector 530 to route an input  
18 channel into a reference channel and a measurement channel. In Fig. 14A,  
19 internal components of the router 500 are shown without the surrounding housing  
20 components and other necessary features known and used in the art to contain  
21 these components. The router 500 has an input collimation optic 510A that  
22 receives the input light signal from an input fiber or bundle 502 that carries the  
23 common optical beam from the multiple sources. The collimated input signal 504

1 from the optic 510A passes to a splitter 520 that splits the input signal 504 into a  
2 measurement signal 506 and a reference signal 508. The measurement signal  
3 506 passing from the splitter 520 reaches an optical element 510C that  
4 condenses the light and images it into a measurement fiber 507. The reference  
5 signal 508 passing orthogonal to the measurement signal 506 reaches the  
6 reflectors 530 (*i.e.*, a right angle prism or other mirrored optical element) that  
7 directs the reference signal 508 to another optical element 510B. Following  
8 collimation by this optic 510B, the reference signal is imaged into the reference  
9 fiber 509.

10 The optical element 510C and input measurement fiber or light path 507  
11 are displaced slightly due to the walk-off induced by the splitter 520. For the  
12 current implementation, the region between the collimator optic 510A and  
13 condensing optic 510B preferably has a nominal distance such that the  
14 transmission performance through the assembly is optimized. The size of the  
15 region may differ, however, depending on the wavelengths, size of optical fibers,  
16 and other factors.

17 The pickoff loss in the splitter 520 is preferably minimized so that the  
18 potential signal that can reach detectors (not shown) is maximized. For this  
19 reason, the splitter 520 is preferably composed of infrared grade fused quartz  
20 with a transmission profile that spans the measurement wavelengths of interest  
21 and minimizes optical losses. For example, the splitter 520 can be a 1-mm thick  
22 fused quartz plate. Other possible materials for the splitter 520 include fused  
23 Silica 0 deg., fused Silica 45 deg., sapphire at 45 Deg., or any other optical

1 material known to those skilled in the art. Adjacent the splitter 520, the right angle  
2 prism 530 allows both fibers or light paths 507/509 to be parallel for mechanical  
3 reasons. Optical element 510B is placed in the same plane as optical element  
4 510C. This is useful for mechanical reasons but may require a different working  
5 distance to the fibers or light paths 507/509.

6 In general, the optics 510A-C as well as other optical elements (*e.g.*,  
7 optics 134; Figs. 3A-3B) disclosed herein can be an achromatic lens, an  
8 achromatic lens pair, a plano-convex lens optically coupled to a bi-convex lens, a  
9 reflective optical element, a mirror, a holographic optical element, or an adaptive  
10 optical element. Fig. 14B shows an arrangement for a collimation optic 510 for  
11 use in the router 500 of Fig. 14A as well as other components disclosed herein.  
12 The optic 510 is a type of achromatic lens having a plano-convex (PCX) lens 512  
13 and a bi-concave lens 514, which can have a physical separation using a spacer  
14 (not shown) or which can be cemented using a suitable optically transmissive  
15 cement. The optical cement used must be able to withstand downhole operating  
16 temperatures. The material types and forms of the two lenses 512/514 are  
17 chosen to have temperature dependent performance characteristics that  
18 maximize optical throughput across the required thermal and spectral ranges.  
19 Thus, as wavelength varies, the focal length of the bi-concave lens 514 changes  
20 more rapidly than that of the plano-convex lens 512. This disparate change in  
21 focal length with wavelength serves to reduce the overall dependence of the  
22 combined focal length over a range of wavelengths.

23

1                   G. Measurement Device and Source Arrangement

2                   In Fig. 15A, a side view of a measurement device 600 has a multi-channel  
3                   source assembly 610 and a detector assembly 660 disposed on a flow body 680.  
4                   For use in a downhole tool, the flow body 680 fits onto a tool chassis (not shown)  
5                   that holds the flow body 680 in place and holds required electronics. In turn, the  
6                   flow body 680 mates with a subassembly (not shown) that routes the flow buses  
7                   in the downhole tool, and the tool chassis fits inside a tool housing (not shown) of  
8                   the downhole tool. Fluid from one of the tool's fluid buses passes through a  
9                   passage 682 from one end of the flow body 680 to the other and passes by the  
10                  source assembly 610 and detector assembly 660.

11                 As shown, the sources assembly 610 can have housings 612/614 that  
12                 couple to the flow body 680. One housing 612 holds the LED sources 620  
13                 arranged on a circuit board 622. The other housing 614 holds an arrangement of  
14                 beam splitters and prisms (630, 640, 650), which are detailed below in Fig. 15B.

15                 For its part, the detector assembly 660 can be similarly configured on the  
16                 opposite side of the flow body 680. Accordingly, one housing 662 attached to the  
17                 flow body 680 houses the photodiode detectors 670 disposed on a circuit board  
18                 672. Also, another housing 664 houses an arrangement of beam splitters and  
19                 prisms (640, 650).

20                 Signals for the measurement and reference channels issue from the  
21                 source assembly 610 and pass to the detector assembly 660 using through-  
22                 space optics (not shown). As disclosed herein, the reference channel can pass  
23                 directly to the detector assembly 660, and the measurement channel can interact

1 with fluid passing through the flow body 680 before passing to the detector  
2 assembly 660. Thus, the measurement channel may pass through a sample  
3 accessory (not shown), such as a sample cell or the like, in the flow body 680.

4 Turning then to the plan schematic view in Fig. 15B, LED sources 620 for  
5 the source assembly 610 are arranged in a matrix or array pattern. Various cube  
6 beamsplitters 630, plate beamsplitters 640, and right angle prisms 650 route the  
7 input signals from the LEDs 620 to a final plate beamsplitter 645 that splits the  
8 input signal into a reference channel and a measurement channel as previously  
9 described. From the source assembly 610, both channels can be routed via  
10 fiber, mirrors, and the like to the detector assembly 660 with its photodiode  
11 detectors 670. For example, through-space optical approaches as well as fiber  
12 routing methods known to those in the art and disclosed herein can be used to  
13 route the channels.

14 As shown, this source assembly 610 has twenty LEDs 620 and several  
15 beamsplitters 640/650 configured for particular wavelengths. The measurement  
16 wavelengths and LED center wavelengths  $\lambda_1$  to  $\lambda_{20}$  can be selected to cover the  
17 spectral channels suitable for downhole real-time analysis of crude or other  
18 downhole fluids. Likewise, longpass filter specifications can be selected for the  
19 measurement wavelengths and LED center wavelengths used. In one example,  
20 the source assembly 610 is configured for measurement wavelengths in the  
21 visible and near infrared spectral regions. As one skilled in the art will appreciate,  
22 the number of LEDs 620 and beamsplitters 640/650 as well as the subject  
23 wavelengths and other values can be configured for a particular implementation.

1                   H. Control circuitry

2           As discussed previously in Fig. 3A-3B, the source assembly 100 uses  
3 control circuitry 160 to control the sources in the source/coupler unit 110. Fig. 16  
4 schematically illustrates one implementation of control circuitry 700 for the  
5 disclosed source assembly. The control circuitry 700 has processing circuitry 720  
6 coupled to a source unit 710, conversion circuitry 730, and an input/output  
7 interface 760. As shown here, the source unit 710 has multiple LEDs 712, but  
8 could have other sources as disclosed herein.

9           The processing circuitry 720 uses programmable control schemes to  
10 control operation of the source assembly 710 and can have a microprocessor or  
11 Field-Programmable Gate Array (FPGA). In operation, the processing circuitry  
12 720 drives the LEDs 712, sets the individual modulation frequencies for the LEDs  
13 712, and performs other control functions discussed below. To drive the LEDs  
14 712, the processing circuitry 720 controls the power from a DC power source 715  
15 to the LEDs 712 using control signals communicated to transistors 714.  
16 Furthermore, the source assembly hardware 710 may be adjusted providing fixed  
17 unique amplitudes for each LED source 712. In addition, the processor 720 may  
18 control LED source amplitude (*i.e.*, intensity) through pulse width modulation or  
19 other means.

20           In driving the LEDs 712, the processing circuitry 720 can modulate each of  
21 the sources at an independent frequency. To modulate the LEDs 712, for  
22 example, the processing circuitry 720 can turn each of the individual sources 712  
23 on and off, modulate each of the individual sources 712 about a mean frequency,

1 or modulate one or more of the individual sources 712 at the same frequency. In  
2 general, the frequency modulation can be in a range between 1 and 20-kHz,  
3 depending on the measurement requirements by the operational mode used (*i.e.*,  
4 either raster scanning, FFT analysis, etc. as described below).

5 The input/output interface 760 has several inputs and outputs, such as a  
6 digital/trigger output 762, a digital/trigger input 764, one or more analog outputs  
7 766, one or more analog inputs 768, and a communications interface (770). The  
8 outputs 762/766/770 of the interface 160 can be used for sending messages to  
9 other systems, such as sending status messages about the operation of the  
10 source assembly, health of the sources 712, *etc.*

11 These inputs and outputs of the interface 760 can be used to interact with  
12 external control circuitry of a detection system (not shown) for external control of  
13 the control circuitry 700. For example, either the analog input 768 or  
14 communications interface 770 can receive control signals used for manual or  
15 automated control of the circuitry's operation. This external control can be from  
16 an external source, such as surface equipment or from a separate downhole  
17 controller. When received, the control signals can configure the control circuitry's  
18 operation to account for variable conditions, such as a change in temperature, a  
19 change in fluid to be analyzed, a change in desired mode of operation to be  
20 used, etc. The external control can also operate the control circuitry 700 to  
21 handle events that require exact timing by using the trigger output 762 and input  
22 764 for triggering signals.

1           In addition to external control, control circuitry 700 can use data from the  
2 analog input 768 as part of an automated control scheme. The conversion  
3 circuitry 730 interposed between the processing circuitry 720 and the input/output  
4 interface 760 uses analog-to-digital conversion (ADC) to convert analog signals  
5 from the analog input 768 into digital signals for the processing circuitry 720 to  
6 process. These analog signals can include amplitude measurements used for  
7 feedback or can include analog control signals for manual or automated control  
8 of the circuitry's operation.

9           In one example, either the analog input 768 or a communications interface  
10 770 can receive control signals from the external control circuitry (not shown)  
11 based on the reference channel amplitude and can use these inputs to control  
12 the operation of the sources 712. In such a situation, the amplitude  
13 measurements can come from a detection system (not shown) configured to  
14 detect optical signals of the reference channel (150). Using those amplitude  
15 measurements as feedback, the control circuitry 700 can then control the  
16 individual sources 712. For example, the control circuitry 700 can maintain a  
17 more uniform intensity profile for the LEDs 712 even when there are significant  
18 changes in environmental conditions. To do this, the processing circuitry 720  
19 can drive the LEDs 712 to maintain a relatively flat illumination profile across the  
20 entire temperature range by using pulse width modulation or other methods of  
21 the drive signals for the LEDs 712.

22           In addition to controlling the LED sources 712 as shown, it will be  
23 appreciated that the control circuitry 700 can include electronic components to

1 illuminate sources other than LEDs and to operate a scanning optic (as in Fig.  
2 3B). The control circuitry 700 can function on its own independent of any  
3 measurements made by a detection unit (not shown). Although analog control is  
4 discussed using analog input 768, the control circuitry 700 can use a digital input  
5 764 to receive digital control signals. In addition, the control circuitry's interface  
6 760 can include additional inputs and outputs, such as an analog output for  
7 sending signals to another downhole controller or for sending signals to a  
8 telemetry unit to relay to surface equipment. For this reason, the control circuitry  
9 700 may include a digital-to-analog convertor circuit 740 and an analog-to-digital  
10 convertor circuit 750.

11

## 12 I. Operational Modes

13 In performing spectroscopy downhole, the multi-channel source assembly  
14 100 (Figs. 3A-3B) can be operated using one or more modes that can give  
15 operators control over scan speed, signal-to-noise ratio, and process monitoring  
16 methodology. For the current explanation, the operational modes are described  
17 in terms of the embodiment of the source assembly 100 having control circuitry  
18 700 and all LED sources 712 as in Fig. 16. However, one skilled in the art will  
19 appreciate that the disclosed operational modes can be modified for any other  
20 source assemblies disclosed herein.

21 For analysis purposes, the reference channel (150) can be spectrally  
22 correlated with the measurement channel (140) so that the data is properly  
23 scaled (*i.e.*, calibrated) as discussed previously. In doing this, the source

1 assembly's control circuitry 700 in conjunction with sample and detection units  
2 (not shown) can analyze a sample's spectral properties (i.e. absorption,  
3 transmission, etc.) using channels (140/150) via raster scanning in continuous  
4 wave (CW) mode, raster scanning in modulated mode with lock-in detection, or  
5 simultaneous modulation with Fast-Fourier Transform (FFT) analysis or other  
6 optical transform approach to spectrally deconvolve the simultaneously  
7 modulated sources 712. In addition to these modes, each source 712 can be  
8 driven at different current levels to control amplitude, which in-turn can improve  
9 signal-to-noise within weak or highly attenuating optical bands.

10 In general, the operational modes for the source assembly 100 can be  
11 implemented as software or the like in the control circuitry 700. Depending on  
12 the implementation, the source assembly's hardware components (FPGA, ADC,  
13 multiplexers, sources, etc.) can be specifically configured to operate under one of  
14 the particular modes. The source assembly's hardware is configured to operate  
15 under all of these different modes. In this way, operating the source assembly  
16 100 in one of the desired modes may simply require programmable changes to  
17 the control circuitry 700, which can occur during installation or even during  
18 downhole use.

19

#### 20 1. Synchronous Encoding

21 In one operational mode, the control circuitry 700 operates the sources  
22 712 using synchronous encoding. In this mode, the control circuitry 700 operates  
23 each source 712, or a limited subset of sources 712, simultaneously with each

1 source 712 being modulated at a unique, independent frequency. The  
2 modulation frequencies used should not share common higher order harmonics.

3 In one example of this mode, the control circuitry 700 illuminates all LED  
4 sources 712 at the same time and modulates the LED sources 712 at unique,  
5 independent frequencies. Operating in this mode allows the measurements  
6 signals to be spectrally de-convolved using fast Fourier transform (FFT) analysis  
7 to produce information for later data processing. In this mode, the analog to  
8 digital sampling rate is used to set the frequency resolution.

9 In an alternative but similar mode, the control circuitry 700 illuminates the  
10 sources 712 using a set of fixed frequencies that have predefined properties. In  
11 particular, the control circuitry 700 pulses the LED sources 712 simultaneously  
12 using fixed frequency increments, and the control circuitry 700 uses waveforms  
13 to pulse the LED sources 712 that are based on an integer number of cycles.  
14 Operating in this mode allows the measurement signals to be spectrally de-  
15 convolved using a predefined numerical method based on the known temporal  
16 characteristics of the waveform to produce information for later data processing.  
17 Ideally, the signal phase shift relative to the modulation frequency is preferably  
18 very small. In addition, the minimum sample period used in the analysis is  
19 preferably greater than  $1/\Delta f$ , where  $\Delta f$  is the frequency increment above the  
20 fundamental frequency ( $f_0$ ) used to illuminate the individual LED sources 712.  
21 Finally, no odd multiples of  $f$  (i.e. 1kHz and 3kHz) are used to pulse the LED  
22 sources 712.

23

1                   2. Asynchronous Encoding

2           In another operational mode, the control circuitry 700 operates the  
3 sources 712 using asynchronous encoding. Here, the control circuitry 700  
4 operates each source 712, or a limited subset of sources 712, in a serial fashion  
5 with only one source illuminated at any point in time. In this mode, for example,  
6 each LED source 712 in the unit 710 is illuminated sequentially one at a time so  
7 that raster scanning can be performed on the signals produced. Alternatively,  
8 each LED source 712 in the unit 710 is illuminated sequentially one at a time with  
9 each LED source 712 being oscillated at a fixed frequency common to all the  
10 LED sources 712. This enables raster scanning with lock-in detection to be  
11 performed.

12

13                   3. Asynchronous Hadamard Transform Encoding

14           In yet another operational mode, the control circuitry 700 operates the  
15 sources 712 using asynchronous Hadamard Transform encoding. In this mode,  
16 the control circuitry 700 operates a unique sequence of a subset of sources 712  
17 in a cyclic fashion with only one subset of sources in operation at a given point in  
18 time. While operating in this mode, each source 712 is modulated at the same  
19 frequencies.

20

21                   J. Source Selection

22           As discussed above, the disclosed source assembly can use various  
23 types of sources to operate across a large band of EM wavelengths used for  
24 spectral analysis. The EM wavelengths can be in the x-ray, gamma, ultraviolet,

1 visible, or infrared range or be in any combination of these ranges. Such EM  
2 radiation has been referred to herein as light or optical signals. Examples of  
3 suitable sources that meet at least some of the previously discussed  
4 specifications for downhole use include multi-channel solid state light emitting  
5 diodes (LED), super-luminescent light emitting diodes (SLED), or laser diodes  
6 (LD) where each of the individual sources have been coupled using a fiber  
7 bundle, a fiber coupler such as a star coupler, a bulk optical coupler, or other  
8 coupler as disclosed herein.

9 In one implementation, each of the sources for the disclosed assembly is  
10 an LED. Depending on the LED's characteristics and the intended application,  
11 these LEDs may or may not use bandpass filters. Using LEDs to define the  
12 measurement wavelengths allows the disclosed source assembly to be made  
13 both compact and versatile in addition to maximizing optical throughput across a  
14 broad spectral range. In addition, by using the optical filters, LEDs with broad  
15 spectral profiles can be used with desired wavelengths that are relatively close  
16 together for performing spectroscopy. This is especially useful for the near-  
17 infrared (NIR) region where a large amount of information in molecular  
18 absorbance data occurs for hydrocarbons, water, and reservoir gases. For  
19 example, a single type of LED can be used to provide source light for 3 or 4  
20 specific bands, since the LEDs can be separately filtered for each wavelength  
21 measurement of interest with a suitable spectral filter. This enables the disclosed  
22 source assembly to meet measurement requirements for particular  
23 implementations.

1                   K. Measurement Device for Downhole Fluid Analysis

2                   As schematically shown in Fig. 17A, the measurement device 30 has a  
3                   source assembly 40, a sample interface assembly 70, and a detector assembly  
4                   800. The source assembly 40 can have one or more spectral sources 42, which  
5                   can include broadband sources (e.g., tungsten halogen lamp, deuterium light  
6                   source, xenon light source, coiled filament IR emitter, arc lamp, metal halide  
7                   lamp, etc.) and solid state electronic sources (e.g., light emitting diode (LED),  
8                   super-luminescent light emitting diode (SLED), laser diode (LD), etc.).

9                   The source assembly 40 generates spectral signals partitioned into two  
10                  channels — a reference channel 50 and a measurement channel 60. The  
11                  reference channel 50 travels directly to the detector assembly 800. The  
12                  measurement channel 60, however, interacts with a sample fluid via the sample  
13                  assembly 70 and then travels to the detector assembly 800. In turn, the detector  
14                  assembly 800 includes a reference detector unit 810 for the reference channel  
15                  50, a measurement detector unit 820 for the measurement channel, and control  
16                  circuitry 830 coupled to these units 810/820. Although one measurement  
17                  channel 50 is shown along with one reference channel 60, it will be appreciated  
18                  that multiple measurements channels 50 can be provided for the same reference  
19                  channel 60. Therefore, the device 30 can have several measurement channels  
20                  50 along with sample assemblies 70 and detector units 80 for separate analysis.

21                  One operational scheme of the measurement device 30 is discussed  
22                  concurrently with reference to Fig. 17B. The detection control circuitry 130  
23                  initiates the source assembly 40 so that the source assembly 40 generates

1 source energy (*i.e.*, spectral signals of EM radiation) with its one or more sources  
2 42 (Block 900). To initiate the source assembly 40, the control circuitry 830 can  
3 trigger source control circuitry (not shown) of the assembly 40, define operational  
4 parameters for the source assembly 40, or perform some other form of  
5 interaction with the assembly 40 (Block 900). For example, the control circuitry  
6 830 can control the source assembly 40 by operating the spectral sources 42  
7 using a specific set of operating parameters (start time, frequency, duty cycle,  
8 *etc.*). The operating parameters specify the encoding of the optical sources  
9 facilitating signal processing after detection. When generating the spectral  
10 signals, for example, the source assembly 40 can encode the signals using  
11 Conventional Raster Scanning (CRS), Fourier Transform (FT), or other encoding  
12 technique for spectroscopic analysis.

13 After generating the signals, the source assembly 40 routes or spectrally  
14 partitions the generated signals into the reference channel 50 and measurement  
15 channel 60 (Block 902). For example, the source assembly 40 can create a first  
16 optical path constituting a first fraction or minority of the generated signals to be  
17 used as the reference channel 50 and can create a second optical path  
18 constituting a second fraction or majority of the generated signals to be used as  
19 the measurement channel 60. In one implementation, the measurement channel  
20 60 constitutes 90% of the generated signals, while the reference channel 50  
21 constitutes 10% of the generated signals, although other percentages could be  
22 used in other implementations. Throughout this disclosure, these channels 50/60  
23 or light paths are referred to as a "measurement channel" and a "reference

1 channel" to indicate that the measurement channel 60 interrogates a sample with  
2 EM radiation while the reference channel 50 is used for dynamic referencing or  
3 other purposes disclosed herein.

4 The spectral signals of the measurement channel 60 interact with a  
5 sample via the sample unit 70 (Block 905). For its part, the sample assembly 70  
6 can use different designs, including, but not limited to, a sample cell, a  
7 reflectance accessory, a transmittance accessory, a fluorescence accessory, an  
8 Attenuated Total Reflectance (ATR) accessory, an extractive flow cell, or any  
9 other sampling or monitoring device known to those skilled in the art.

10 The reference and measurement channels 50 and 60 are collected by the  
11 detector units 810 and 820, respectively (Block 903/906). For example, the  
12 reference detector unit 810 detects the spectral signals and sends detected  
13 reference signals to the control circuitry 830 (Block 903). In detecting these  
14 signals, the reference detector unit 810 can detect one or more spectral bands  
15 using one or more spectral detectors as detailed below. After interaction with the  
16 sample, for example, the measurement detector unit 820 detects the spectral  
17 signals and sends detected measurement signals to the control circuitry 830  
18 (Block 906). As with the reference detector unit 810, the measurement detector  
19 unit 820 can detect one or more spectral bands with one or more detectors.

20 At this point, the control circuitry 830 processes the output of the one or  
21 more detectors for the channels 50/60 (Block 904/907) and scales, if necessary,  
22 the output of each measurement detector using the corresponding reference  
23 detector signal (Block 908). This dynamic scaling can account for source

1 anomalies due to downhole environmental conditions, aging, or the like. Once  
2 processed and scaled, the processed signals provide information that can be  
3 used to correlate the spectral response with specific fluid properties and  
4 characteristics, and the resulting spectral data can be used to determine  
5 chemical and/or physical properties of the sample fluid. This can be performed  
6 by the control circuitry 830 itself or by some other controller. Ultimately, as  
7 referenced above, the measurement device 30 of Fig. 1 can transmit spectral  
8 data to a processing system (not shown) located on the tool 10 or at the surface  
9 equipment 28.

10 At some point during processing, the control circuitry 830 determines if the  
11 output of the source assembly 40 needs to be modified (Decision 909). If no  
12 modification is necessary, operation continues using the operating parameters  
13 originally specified. If modification is necessary, however, the source assembly  
14 40 is re-initiated with a new set of operational parameters (Block 910). For  
15 example, the source(s) 42 in the source assembly 40 may be operated using  
16 pulse width modulation, and the control circuitry 830 can configure a modulated  
17 pulse train used to operate the sources 42 with specific characteristics, such as  
18 modulation amplitude and frequency. In such an instance, the control circuitry  
19 830 may modify the source assembly's output by signaling the source assembly  
20 40 to make a necessary adjustment or by configuring and supplying temporal  
21 characteristics for the pulse train to be used by the source assembly 40 in  
22 generating the spectral signals (Block 910). In general, these pulse train

1 temporal characteristics can include, but are not limited to start time, pulse  
2 frequency, duty cycle, and pulse shape.

3

#### 4 A. Downhole Multi-Channel Detector Assembly

5 With an understanding of the measurement device 30 and the downhole  
6 tool 10 in which it can be deployed, discussion now turns to different  
7 arrangements of a multi-channel detector assembly 800 for downhole  
8 spectroscopy according to certain teachings of the present disclosure.

9

##### 10 1. Single Detector Arrangement

11 In a first arrangement shown in Fig. 18, the multi-channel detector  
12 assembly 800 is set up with a single detector arrangement for each channel  
13 50/60. As shown, the detector units 810A/820A each have a single detector  
14 812/822 for detecting one beam or band of spectral energy from their respective  
15 channel 50/60. In general, the detectors 812/822 in the units 810/820 can use  
16 any of the various available configurations (*i.e.*, single or multiple element  
17 photodiodes (PD), avalanche photodiodes (APD), photomultiplier tubes (PMT),  
18 Multi-Channel Plates (MCP), bolometers, thermopiles, *etc.*) and can have a  
19 sensing substrate composed of Si, SiC, InGaAs, InAlGaAs, Pbs, PbSe, or any  
20 other known material for sensing spectral radiation. For example, the detectors  
21 812/822 can be photodiodes capable of sensing in the near infra-red (NIR),  
22 ultraviolet (UV), and/or visible (Vis) spectrum, or in some other spectral range  
23 depending on the implementation.

1 In operation, the detectors 812/822 detect spectral signals from the  
2 channels 50/60 in the specific band used, and the control circuitry 130 receives  
3 the output from the detectors 812/822 for processing and analysis. As noted  
4 above, for example, the reference channel 50 can then be used as optical  
5 feedback for controlling the source assembly (40) and/or to dynamically scale the  
6 spectral signal of the measurement channel 60.

7 In general, the spectral signals of each channel 50/60 can pass through  
8 free space using a series of discrete optical elements in a non-fiber based  
9 arrangement. Alternatively as shown, the spectral signals of each channel 50/60  
10 can be carried from the source assembly (40) by a fiber optic cable 52/62 and  
11 imaged onto the detector 812/822 using an optical coupling. In Figs. 19A-19B, a  
12 representative optical coupling 1000 is shown that can be used in this  
13 arrangement. This coupling 1000 images a fiber optic cable 52 onto a single  
14 photodiode of detector 812 (shown here for the reference channel 50). A  
15 collimating lens 1002 and a focusing lens 1004 position in a lens housing 1008  
16 separated by a lens spacer 1006. The housing 1008 with lenses 1002/1004  
17 attaches to the photodiode of detector 812, which has a header 1005 and a  
18 window 1007. On the other end, a fiber-ferrule assembly 1010, strain relief boot  
19 1012, ferrule mounting tube 1014, and alignment sleeve v16 couple the fiber 52  
20 to the housing 1008. It will be appreciated that, besides this optical coupling  
21 1000, other fiber and non-fiber-based arrangements could be used to image the  
22 spectral signals from the channels 50/60 onto the detectors 812/822.

23

## 2. Dual Detector Arrangement

1                                   2. Dual Detector Arrangement  
2           In a second arrangement shown in Fig. 20, the multi-channel detector  
3 assembly 800 is set up with a dual detector arrangement for the reference and  
4 measurement channels 50/60. As shown, each detector unit 810B/820B has  
5 dual detectors 812A-B/822A-B for detecting two beams or bands of spectral  
6 energy from their respective channels 50/60. For example, first detectors  
7 812A/822A can be photodiodes capable of sensing in the near infra-red (NIR)  
8 spectrum, while second detectors 812B/822B can be photodiodes capable of  
9 sensing in the ultraviolet (UV)/visible (Vis) spectral ranges, although other  
10 spectral ranges could be used. In combination, each dual band detector unit  
11 810B/820B can detect a wavelength range of about 350 to about 2400-nm, for  
12 example.

13           A router assembly inside each dual band detector unit 810B/820B  
14 partitions the spectral signals of the channels (50/60) into separate or different  
15 beams or bands and routes those beams or bands to individual detectors. (In  
16 general, there may be some overlap between the spectral bands in the two  
17 beams.) Inside each unit 810B/820B, for example, a high pass beam splitter  
18 816/826 splits the incoming channel (50/60) into a first (NIR) band and a second  
19 (UV-Vis) band by reflecting all wavelengths shorter than a cutoff wavelength and  
20 by passing all longer wavelengths, or vice versa. In one implementation, the  
21 cutoff wavelength of the splitter 816/826 can be between 900 and 1000-nm. In  
22 general, the splitter 816/826 can be a dichroic element (e.g. mirror), a high pass

1 filter, a low pass filter, a partial metalized mirror, or any optical elements known in  
2 the art that can partition the spectral signals into discrete spectral bands.

3       Once the channels (50/60) are split into bands, the first (NIR) detectors  
4 812A/822A detect the first isolated bands passing through the splitters 816/826.  
5 These first (NIR) detectors 812A/822A can be InGaAs photodiodes used for  
6 sensing the NIR wavelength range, for example. Likewise, the second (VIS)  
7 detectors 812B/822B detect the second isolated bands from the splitters  
8 816/826. These second (VIS) detectors 812B/822B can be silicon-based  
9 photodiodes used for sensing the visible and/or ultraviolet wavelength range, for  
10 example. After detection, the control circuitry 830 coupled to each of the  
11 detectors 812A-B/822A-B interrogates the detectors' responses for processing  
12 and analysis.

13       Figs. 21A-21C show embodiments of a dual detector unit 810B for the  
14 reference channel (50) in more detail, although some of the surrounding  
15 components for housing the unit's elements are not shown for simplicity. (The  
16 dual detector unit 820B for the measurement channel can be similarly  
17 configured.) A fiber optic cable 52 carries the spectral signals of the reference  
18 channel (50), and a router assembly having lens optics 814 and splitter 816  
19 partitions the signals and routes separate or different bands to the dual detectors  
20 812A-B. In particular, a first lens optic 814 collimates the signal from the fiber  
21 optic cable 52. The collimated signal passes to the splitter 816 that splits the  
22 energy into the two bands, one for the first detector 812A and another for the  
23 second detector 812B. Additional lens optics 814 then image the separate or

1 different bands to the photodiode dies of the detectors 812A-B. As shown in Fig.  
2 21A, the detectors 812A-B can be arranged perpendicularly. Alternatively, they  
3 can be arranged at an acute angle as in Fig. 21B.

4 In Fig. 21C, the dual band detector unit 810B for the reference channel  
5 (50) has a router assembly with an adaptive optic element 811 for partitioning the  
6 reference channel (50). As before, fiber optic cable 52 carries the spectral  
7 signals of the reference channel (50), and the router assembly has a lens optic  
8 814 that collimates the signal from the fiber optic cable 52. At this point, the  
9 router assembly uses its adaptive optic element 811 that oscillates between two  
10 or more orientations to partition the input signals into separate beams  
11 alternately routed to the dual detectors 812A-B. The adaptive optic element 811  
12 can be a scanning mirror, such as a micro-electro-mechanical (MEM) mirror  
13 device or a Micro-Electro-Mechanical System (MEMS) scanning mirror.

14 A first beam reflected from the element 811 passes to a first lens optic 814  
15 that images the beam to the first detector 812A, and a second beam reflected  
16 from the element 811 passes to a second lens optic 814 that images the beam to  
17 the second detector 812B. One benefit with the arrangement in Fig. 21C is that  
18 there is no optical loss due to a beam splitter. Consequently, all optical energy in  
19 the system may be transmitted to each detector 812A-B. With the configuration  
20 shown in Fig. 21C, it is also easy to envision having multiple measurement  
21 channels and a single reference channel.

22 In one implementation, the two beams from the adaptive optic element  
23 811 can be the same bands (*i.e.*, can have the same spectral range of

1 wavelengths), and the lens optics 814 for the separate detectors 812A-B may be  
2 filters filtering different wavelengths in the common spectral range. In another  
3 implementation, the adaptive optic element 811 can have a grating on its surface  
4 so that different spectral bands are reflected from the element 811 at different  
5 angles. In this way, one of the beams reflected from the grated element 811 can  
6 have one specific spectral range for the first detector 812A that is different than  
7 that for the second detector 812B.

8 In general, the lens optics 814 of Figs. 21A-21C can be an achromatic  
9 lens, an achromatic lens pair, a plano-convex lens optically coupled to a bi-  
10 convex lens, etc. Fig. 22 shows an exemplary lens optic 814 that can be used  
11 for the routers disclosed herein. The lens optic 814 is a type of achromatic lens  
12 having a plano-convex (PCX) lens 815 and a bi-concave lens 817, which can  
13 have a physical separation using a spacer (not shown) or which can be  
14 cemented together using a suitable optically transmissive cement. The optical  
15 cement used must be able to withstand downhole operating temperatures. The  
16 material types and forms of the two lenses 815/817 are chosen to have offsetting  
17 focal length effects. Thus, as wavelength varies, the focal length of the bi-  
18 concave lens 817 changes more rapidly than that of the plano-convex lens 815.  
19 This disparate change in focal length with wavelength serves to reduce the  
20 overall dependence of the combined focal length over a range of wavelengths.

21 Fig. 23 shows a dual band detector unit 810B for the reference channel  
22 (50) using the exemplary lens optic 814 of Fig. 22. In the router assembly, an  
23 input lens optic 814A receives the spectral signal from the fiber optic cable 52 for

1 the reference channel (50), and the optic 814A collimates the signal. The splitter  
2 816 then splits the collimated signal into the two bands as described previously,  
3 allowing longer wavelengths to pass through the splitter 816 and reflecting  
4 shorter wavelengths. One band passing from the splitter 816 reaches another  
5 lens optic 814B which condenses the signal and images it onto the die of the first  
6 (NIR) detector 812A. The other band reflected from the splitter 816 reaches a  
7 reflector 818.

8 Although shown here as a right angle prism, the reflector 818 can be a  
9 mirror or other comparable optical element. The reflector 818 directs this band to  
10 another lens optic 814C, which condenses the signal and images it onto the die  
11 of the second (UV/Vis) detector 812B. The reflector 818, therefore, allows both  
12 bands to run parallel to one another and allows the two detectors 812A-B to be  
13 packaged together. Not only does this conserve space, which is important in a  
14 downhole tool, but being able to package the two detectors 812A-B together  
15 enables them to be arranged co-planar to one another and to experience the  
16 same environmental changes, such as the same overall thermal conditions.

17

### 18 3. Multi-Detector Arrangement

19 As discussed above, the detector assembly 800 in FIG. 18 represents a  
20 single detector arrangement capable of sensing in one band or spectrum, *e.g.*,  
21 near infra-red (NIR) or ultraviolet (UV)/visible (Vis) spectral ranges, while the  
22 detector assembly 800 in FIG. 20 represents a dual detector arrangement that  
23 can simultaneously measure and reference in two bands or spectral ranges, *e.g.*,

1 the UV-Vis and NIR ranges. As noted previously, the dual detector units  
2 810B/820B can be used to cover a measurement range of interest from about  
3 350-nm to about 2400-nm. However, additional detectors could also be included  
4 in the unit 810B/820B to either further partition the range into discrete bands or to  
5 extend the range to cover a wider spectral range, such as from about 200-nm to  
6 over 3000 nm.

7 In Fig. 24A, for example, a multi-detector unit 810C has a router assembly  
8 with a series of low pass filters 816 that filter the spectral signals from the  
9 reference fiber optic cable 52 in stages of beams or bands to a series of  
10 reference detectors 812. Again, lens optics 814 image the collimated signals to  
11 the diode dies of the detectors 812. Because low pass filters 116 are used, the  
12 various combinations of detectors 812 and low pass filters 816 can decrease in  
13 wavelength ( $\lambda_7 - \lambda_0$ ) as they are positioned further away from the fiber optical  
14 cable 52 so that shorter wavelengths (higher frequencies) will reach further  
15 detectors 812. A reverse arrangement could also be used in which a series of  
16 high pass filters (as opposed to low pass filters) are used, and the combination of  
17 detectors 812 and high pass filters 816 can increase in wavelength ( $\lambda_0 - \lambda_7$ ) as  
18 they are positioned further away from the fiber optic cable 52 so that longer  
19 wavelengths (lower frequencies) will reach further detectors 812.

20 In addition to the above arrangements, Fig. 24B shows a multi-detector  
21 unit 810D having multiple detectors 812, lenses 814, and filters 816 having a  
22 clustered router arrangement. The filters 816 direct and split off wavelengths of  
23 interest from the reference fiber optic cable 52 to the various detectors 812 in a

1 similar way to that discussed previously, but with a more compact arrangement  
2 that limits the number of filter passes per spectral band.

3

4 B. Housing Arrangements For Multi-Channel Detector Assembly

5 Because the detector assembly 800 is used downhole, housing its  
6 components can be constrained by the available tool space and the downhole  
7 environmental specifications. Ideally, components of the detector assembly 800  
8 have a housing that is amenable to downhole deployment and that can fit into the  
9 tight downhole space required in a downhole tool. Therefore, the detector  
10 assembly 800 is preferably constructed as a discrete modular unit that can be  
11 incorporated or connected to other modular units, such as modular units for the  
12 source assembly (40) and sample assembly (70) in a downhole tool.

13 Because multiple detectors 812/822 are used and are subject to  
14 potentially changing environmental parameters such as temperature, the  
15 particular detectors 812/822 used are preferably mapped to determine how  
16 changes in their responsivity occur as a function of changes in environmental  
17 parameters. This mapping can then be used to match the detector's responsivity  
18 during use downhole to the real-time environmental changes occurring during  
19 operation. This enables the use of multiple detectors 812/822 despite the fact  
20 that such a multiple detector approach has been viewed as impractical in the art  
21 due to variations in detector-to-detector responsivity and operation. Ideally, the  
22 detectors 812/822 are also preferably super-matched to further reduce the  
23 detector-to-detector differences in environmentally induced responsivity and are

1 preferably co-packaged in a single housing to reduce electronic and mechanical  
2 packaging complexity.

3

#### 4 C. Control Circuitry

5 The multi-channel detector assembly 800 is schematically shown in more  
6 detail in Fig. 25, illustrating additional components of the control circuitry 830. As  
7 shown, the control circuitry 830 has conversion circuitry 840, signal processing  
8 circuitry 850, and an input/output interface 860. The conversion circuitry 840  
9 connects to the detector units 810B/820B. The signal processing circuitry 850  
10 receives detected signals from the conversion circuitry 840 and connects to the  
11 interface 860. In turn, the interface 860 connects to external transducers 80  
12 through inputs 868 and connects to other components of the measurement  
13 device using digital and analog inputs/outputs 862/864. The interface 860 can  
14 also connect to suitable memory 870.

15 The detector units 810B/820B shown here are for the dual band  
16 arrangement. Therefore, the reference detector unit 810B has dual detectors  
17 812A-B, and the measurement detector unit 820B has dual detectors 822A-B.  
18 Splitters 816/826 split the reference and measurement channels 50/60 into the  
19 two bands for the detectors 812A-B/822A-B as discussed previously. The  
20 conversion circuitry 840 receives the detected signals from the detectors 812A-  
21 B/822A-B and digitizes the detected analog signals for each channel 50/60.

22 To handle the analog signals from the detectors 812A-B/822A-B, the  
23 conversion circuitry 840 has gain circuits 842 that can include photodiode

1 detector circuitry, analog filters, and amplifiers for each of the detectors 812A-  
2 B/822A-B. The gain circuits 842 can use a nominally zero bias photovoltaic  
3 operation and can be configured to handle various sources of noise, such as  
4 signal shot noise, dark current shot noise, shunt resistance thermal (Johnson)  
5 noise, *etc.*

6 From the gain circuits 842, the analog detector signals pass to analog-to-  
7 digital conversion (ADC) circuitry 844 that converts the analog detector signals  
8 into digital signals for the signal processing circuitry 850 to process. For this dual  
9 band arrangement, the ADC circuitry 844 can use four A/D conversion inputs  
10 with two inputs for the two reference channel bands from the reference detectors  
11 812A-B and two inputs for the two measurement channel bands from the  
12 measurement detectors 822A-B. The multiple A/D conversion inputs of the  
13 circuitry 144 can be part of an integrated chip (IC) (*i.e.*, a 4, 8, or 16 channel A/D)  
14 or can utilize multiple single channel A/D's. When using frequency modulation,  
15 the A/D conversion speed is preferably at least 8 times the maximum modulation  
16 frequency used to encode the spectral signals to ensure proper sampling.

17 After the ADC circuitry 844 converts the analog detector signals to digital  
18 signals, the signal processing circuitry 850 receives the digital signals and uses  
19 programmable control schemes to process the signals (*i.e.*, to compare the  
20 signals for the two channel (50/60), to compare the signals for each channel's  
21 bands, to control operation of the assembly 800, to perform spectral data  
22 analysis, to package data for up-hole communication, *etc.*). Using the digital  
23 signals, for example, the signal processing circuitry 850 performs digital filtering

1 (lock-in detection), absolute value conversion, RC filtering, averaging of the raw  
2 intensity signals, and/or Fast-Fourier Transform or similar de-convolution  
3 techniques, among other functions. In general, the signal processing circuitry  
4 850 can have a microprocessor or Field-Programmable Gate Array (FPGA) and  
5 other appropriate electronics.

6 After processing the signals, the control circuitry 830 can store information  
7 in memory 870 and can communicate information to other components (e.g.,  
8 source assembly (40), another controller, telemetry unit, etc.) using the  
9 input/output interface 860 and any of the various known techniques. In general,  
10 the control circuitry 830 can communicate processed information uphole in real-  
11 time as one or more data sets that include all raw data, partial raw data,  
12 averages, and the like. In one example, the control circuitry 830 can  
13 communicate an average raw intensity from both the measurement and  
14 reference detectors units 810B/820B in the separate bands (NIR and UV/Vis).  
15 Transmitting both of these data sets uphole allows operators at the surface to  
16 review each data set, thereby enhancing diagnostic capabilities for setting data  
17 integrity flags. In another example, the control circuitry 830 can communicate  
18 processed signal data, such as ratios. In this way, only a single data set needs  
19 to be transmitted. Regardless of how data is communicated, processing  
20 equipment at the surface can analyze the data and convert the data into unique  
21 values.

22 In general, the control circuitry 830 can operate as a standalone controller  
23 that communicates (sends and receives) triggers with the source assembly (40),

1 which can have its own controller, so that the control circuitry 830 can coordinate  
2 its operation with that of the source assembly (40). Alternatively, the control  
3 circuitry 830 can implement direct control of the source assembly (40) by actually  
4 configuring some of the source assembly's operational parameters and sending  
5 control signals, parameters, and/or triggers to the source assembly (40) to  
6 implement. In yet additional alternatives, the source assembly (40) may actively  
7 control the detector assembly 800 by configuring some of its operational  
8 parameters, or an entirely separate controller can control both the source  
9 assembly (40) and the detector assembly 800.

10 As shown, the input/output interface 860 has inputs 862 and outputs 864  
11 that can be analog and digital and has a scaled signal output 866 and inputs 868  
12 for external transducers 80. The interface 860 can be used for triggering and  
13 external control of other control components, such as a controller of the source  
14 assembly (40; Fig. 17A). The interface 860 can also receive control signals used  
15 for manual or automated control of the circuitry's operation. This external control  
16 can be from an external source, such as a controller of the source assembly (40),  
17 surface equipment, or from a separate downhole controller. When received, the  
18 control signals can configure the control circuitry 830's operation to account for  
19 variable conditions, such as a change in temperature, a change in fluid to be  
20 analyzed, a change in desired mode of operation to be used, etc. The external  
21 control can also operate the control circuitry 830 to handle events that require  
22 exact timing by using the digital inputs and outputs 862/864 for triggering signals.

23

1                   D. Measurement Device and Source Arrangement

2           In Fig. 26, a side view of a measurement device 1100 has a multi-channel  
3   source assembly 1110 and a detector assembly 1160 disposed on a flow body  
4   1180. For use in a downhole tool, the flow body 1180 fits onto a tool chassis (not  
5   shown) that holds the flow body 1180 in place and holds required electronics. In  
6   turn, the flow body 1180 mates with a subassembly (not shown) that routes the flow  
7   buses in the downhole tool, and the tool chassis fits inside a tool housing (not  
8   shown) of the downhole tool. Fluid from one of the tool's fluid buses passes through  
9   a passage 1182 from one end of the flow body 1180 to the other and passes by the  
10   source assembly 1110 and detector assembly 260.

11           As shown, the source assembly 1110 can have housings 1112/1114 that  
12   couple to the flow body 1180. One housing 1112 holds the LED sources 1120  
13   arranged on a circuit board 1122. The other housing 1114 holds an arrangement  
14   of beam splitters and prisms (1130, 1140, 1150).

15           For its part, the detector assembly 1160 can be similarly configured on the  
16   opposite side of the flow body 1180. Accordingly, one housing 1162 attached to  
17   the flow body 1180 houses the photodiode detectors 1170 disposed on a circuit  
18   board 1172. Also, another housing 1164 houses an arrangement of beam  
19   splitters and prisms (1140, 1150), which are detailed below in Fig. 27.

20           Signals for the measurement and reference channels issue from the  
21   source assembly 1110 and pass to the detector assembly 1160 using through-  
22   space optical elements (not shown). The reference channel can pass directly to  
23   the detector assembly 1160, and the measurement channel can interact with fluid

1 passing through the flow body 1180 before passing to the assembly 1160. Thus,  
2 the measurement channel may pass through a sample accessory (not shown),  
3 such as a sample cell or the like, in the flow body 1180.

4 Turning then to the plan schematic view in Fig. 27, both channels can be  
5 routed via fiber, mirrors, and the like to the detector assembly 1160. For  
6 example, through-space optical and fiber routing approaches known to those in  
7 the art or disclosed herein can be used to route the channels to the detector  
8 assembly 1160. First photodiode detectors 1170 receive the reference channel  
9 and have a plate beamsplitter 1140 and right angle prism 1150. Likewise,  
10 second photodiode detectors 1170 receive the measurement channel and  
11 similarly have a plate beamsplitter 1140 and right angle prism 1150.

12 As shown, the detector assembly 1160 has two photodiode detectors  
13 1170 for each channel with one detector 1170 receiving wavelengths <1000-nm  
14 and the other receiving wavelengths >1000-nm. The plate beamsplitters 1140  
15 can have a cut-on wavelength intermediate to the detector ranges and either  
16 transmit above the cut-on or reflect below the cut-off. These details are meant to  
17 be merely exemplary, as one skilled in the art will appreciate that the number of  
18 detectors 1170 and beamsplitters 1140 as well as the subject wavelengths and  
19 other values can be configured for a particular implementation.

20

#### 21 E. Dynamic Referencing

22 Being deployed downhole, the measurement device (30; Fig. 17A) can  
23 exhibit sensitivities to environmental stresses. However, the detector assembly

1 800 spectrally correlates the reference and measurement channels 50/60 by  
2 using the reference channel 50 for real-time scaling so that various  
3 environmental effects can be accounted for during operation and analysis.  
4 Although the detectors 812/822 may still respond differently to changes in  
5 environmental conditions, through calibration, it is possible to scale the output of  
6 the measurement detectors 822A-B with the output of the reference detectors  
7 812A-B, thereby compensating for environmental induced spectral changes in  
8 the source assembly (40) or environmentally induced responsivity changes of the  
9 detectors 812A-B/822A-B in real-time. In addition, the control circuitry 830 can  
10 use the reference channel (50) as real-time feedback to control operation of the  
11 source assembly (40) and to dynamically improve the signal-to-noise ratio  
12 through real-time control of spectral acquisition parameters.

13

14 1. Correlating Detected Signals using Dynamic Referencing

15 In dynamic scaling, for example, the control circuitry 830 uses the  
16 reference channel (50) to dynamically scale the measurement channel (60). To  
17 do this scaling, the signal processing circuitry 850 first processes the  
18 measurement and reference channels (50/60) by deconvolving their detected  
19 spectral signals based on the type of encoding used to encode the signals output  
20 by the source assembly (40). Depending on the implementation, for example,  
21 the circuitry 850 can deconvolve the signals based on Conventional Raster  
22 Scanning (CRS) encoding, Fast Fourier Transform (FFT) encoding, other  
23 temporal encoding, Hadamard encoding, other spectral encoding, or the like.

1 Then, the signal processing circuitry 850 temporally syncs the deconvolved  
2 measurement and reference signals and scales the amplitude values of the  
3 deconvolved measurement signal using the amplitude values of the deconvolved  
4 reference signal.

5 The result of this scaling is a measurement signal (866) that has been  
6 corrected in real-time for variations caused by disparate responses, such as but  
7 not limited to temperature changes, drift in the source (42) operation, and drift in  
8 the detector assembly's electronics. The output 866 of the interface 860 can  
9 then send the scaled signal to other components of the measurement device (30;  
10 Fig. 17A), such as the source assembly (40), another controller, or other  
11 destination.

12

## 13 2. Configuring Source Assembly using Dynamic Referencing

14 In addition to correlating detected signals, the control circuitry 830 can use  
15 the response from the reference detectors 812A-B as feedback to configure the  
16 output of the source assembly (40) so the source assembly (40) can maintain a  
17 relatively flat or consistent illumination profile across an entire temperature range  
18 that may be experienced downhole. To do this, the control circuitry can use the  
19 detected signals from the reference channel (50) as an indication when changes  
20 in pulse width modulation, intensity, or the like need to be made for the spectral  
21 signals output from the source assembly (40) so that the signals for both the  
22 measurement and reference channels (50/60) are improved.

1           In addition to determining changes directly through dynamic referencing,  
2   the control circuitry 830 can also receive data of environmental conditions  
3   downhole from one or more external transducers 80, including but not limited to  
4   pressure and temperature transducers. The control circuitry 830 can then use  
5   these environmental conditions measured downhole in conjunction with the  
6   dynamic referencing of the reference channel (50) to compensate the operation  
7   of the detector units 810B/820B and the source assembly (40) to account for  
8   issues with temperature changes, drift in the source's operation, and drift in the  
9   assembly's electronics caused by such environmental conditions. For example,  
10   the control circuitry can use the information from the external transducers as  
11   input to a scaling function or a lookup table employed to scale the processed  
12   measurement signal. This scaling can thereby account for spectral changes that  
13   would be caused by the environmental conditions detected by the transducers.

14           To configure the output of the source assembly (40), the control circuitry  
15   830 can trigger the source assembly (40), which may have its own controller, to  
16   change its operating parameters to account for the environmental changes  
17   determined through the dynamic referencing and/or external transducers 80.  
18   Alternatively, the control circuitry 830 can directly control the source assembly  
19   (40) by configuring its operating parameters and sending control signals to the  
20   assembly (40) for operation.

21           In one brief example of such direct control, the control circuitry 830 can  
22   initially configure how the sources (42) in the source assembly (40) are to be  
23   operated and can send control signals to the source assembly (40) to implement

1 the configured operation. For example, the control circuitry 830 may configure  
2 the amplitude at which to operate the sources (42), thereby altering or increasing  
3 the overall optical intensity of the signals. Alternatively, the control circuitry 830  
4 may configure one or more modulated pulse trains used for controlling the  
5 illumination of the sources (42) and can send temporal characteristics (start time,  
6 pulse frequency, duty cycle, or pulse shape) of the pulse trains to the source  
7 assembly (40) to implement when operating the sources (42).

8 As the source assembly (40) then generates spectral signals as  
9 configured, the control circuitry 830 detects the spectral signals generated by the  
10 source assembly (40) using the reference detector unit 810B. By comparing the  
11 detected signal to how the output is configured for the source, the signal  
12 processing circuitry 850 can determine what discrepancies exist between how  
13 the source assembly (40) is being operated and how the spectral signals are  
14 being detected, and the control circuitry 830 can correlate any discrepancies to  
15 spectral changes caused by the environmental conditions. Based on this  
16 analysis, the control circuitry 830 can then make modifications to how it controls  
17 the source assembly (40), thereby controlling the illumination and resulting  
18 amplitude of the source assembly (40) to maintain a relatively flat or consistent  
19 illumination profile despite large environmental changes.

20

#### 21 F. Detection/Signal Processing Modes

22 In addition to dynamic referencing, the detector assembly 800 can be  
23 operated in one or more detection/signal processing modes that can give

1 operators control over scan speed, signal-to-noise ratio, and process monitoring  
2 methodology. In general, these processing modes for the detector assembly 800  
3 can be implemented as software or the like in the control circuitry 830.  
4 Depending on the implementation, the assembly 800's hardware components  
5 (FPGA, ADC, multiplexers, etc.) can be specifically configured to operate utilizing  
6 one of the particular modes or can be configured to operate under several of  
7 these different modes. In this way, operating the detector assembly 800 in one  
8 of the desired modes may simply require programming changes to the control  
9 circuitry 830, which can occur during installation or even during downhole use via  
10 the interface 860. Depending on the implementation, the detection and signal  
11 processing in each of these modes may be performed separately on each  
12 channel 50/60 using the spectral signals from the separate detection units  
13 810/820. Likewise, the processing of each channel 50/60 may be performed  
14 separately on the detected bands from each detector in the multi-band  
15 arrangements.

16

17 **1. Conventional Raster-Scanning Mode**

18 In a first detection/signal processing mode, the detector assembly 800 can  
19 be operated using raster-scanning. In this mode, the control circuitry 830  
20 configures the source assembly (40) to illuminate each source (42) sequentially  
21 one at a time, and the control circuitry 830 can correlate both the reference and  
22 measurement channel (50/60) measurements for each source (42) in a serial

1 fashion, thereby acquiring a full spectral scan over time. This mode does not  
2 require source modulation.

3 Alternatively, the control circuitry 830 configures the source assembly (40)  
4 to illuminate each source (42) sequentially one at a time with each source (42)  
5 being oscillated at a fixed frequency common to all the sources (42) to improve  
6 the signal-to-noise ratio. Then, the control circuitry 830 can perform raster  
7 scanning with lock-in detection of the reference and measurement channels  
8 (50/60) detected by the detector units 810B/820B. The lock-in detection can be  
9 implemented by digital filtering, absolute value determination, averaging and any  
10 other techniques known to those skilled the art of signal analysis.

11 Either way, the reference and measurement channels (50/60) are  
12 immediately correlated, and the modulated signal received at the reference and  
13 measurement detector units 810B/820B can then be used during data  
14 processing. Operation of the detector assembly 800 in this mode can allow for  
15 easy noise level versus integration time tradeoffs. Ultimately, the control circuitry  
16 830 needed to operate in this mode may require less complexity which may be  
17 beneficial for downhole use.

18

## 19 2. Channel Select Raster Scanning

20 A second detection/signal processing mode is a modified form of raster  
21 scanning. In this mode, the control circuitry 830 configures the source assembly  
22 (40) to illuminate a reduced number of the available spectral sources (42) (e.g.,  
23 LEDs) in the source assembly (40). When a change is detected in the spectral

1 bands for these select sources (42), the control circuitry 830 configures the  
2 source assembly (40) to operate under full raster-scanning mode as discussed  
3 above so that a complete spectral scan can be run for further discrimination of  
4 the sample fluid being measured. This modified raster-scanning mode allows  
5 the detector assembly 800 to run relatively fast and with more flexibility in  
6 meeting the requirements of an intended application.

7

### 8 3. Fast-Fourier-Transform (FFT) Mode

9 In a third detection/signal processing mode, the control circuitry 830  
10 configures the source assembly (40) to illuminate all the sources (42) (e.g.,  
11 LEDs) of the source assembly (40) simultaneously so their spectral signals can  
12 all be processed simultaneously. This FFT mode offers synchronous full spectral  
13 scanning of the fluid properties and can also lead to an improved signal-to-noise  
14 (S/N) ratio under most environmental conditions. To operate under this FFT  
15 mode with the source assembly (40) having multiple sources (42) such as LEDs,  
16 the control circuitry 830 may need to simultaneously process in excess of 256  
17 channels of data for the dual band arrangement of the detector assembly 800 as  
18 in Fig. 25.

19 In this mode, the control circuitry 830 configures the sources (42) to  
20 illuminate the sample in the sample assembly (70; Fig. 17A) simultaneously with  
21 all sources (42), and the detector assembly 800 uses FFT operations for single  
22 shot data acquisition across the entire measurement range. To do this, the  
23 control circuitry 830 configures each source (42) to modulate at an independent

1 frequency, and the control circuitry 830 de-convolutes the signals detected from  
2 the measurement and reference detector units 810B/820B using FFT analysis to  
3 provide intensity information for later data processing. In this mode, a sample  
4 time is used to set the frequency resolution. In addition, the amplitude accuracy  
5 of the measurement is set by an Analog-to-Digital converter's bit resolution, the  
6 sample duration and frequency, the number of scans averaged, and the signal-  
7 to-noise ratio of the detector units 810/820.

8

#### 9 4. Fixed Frequency Analysis (FFA) Mode

10 In a fourth detection/signal processing mode, which is similar in terms of  
11 simultaneous excitation to the FFT mode, the detector assembly 800 uses a fixed  
12 frequency analysis (FFA) mode in which a set of fixed frequencies that have  
13 predefined properties are used for illuminating the sources (42) (e.g., LEDs).  
14 Referring concurrently to the detector assembly 800 in Fig. 25 and a process  
15 1200 in Fig. 28, the control circuitry 830 in this FFA mode configures the sources  
16 (42) to pulse simultaneously using fixed frequency increments, and the control  
17 circuitry 830 configures the waveforms to pulse the sources (42) based on an  
18 integer number of cycles. To do this, the control circuitry 830 can define the  
19 temporal characteristics (start time, frequency, duty cycle, and phase delay) of a  
20 modulated pulse train used for operating the sources (42) based on the fixed  
21 frequency increments and predefined properties (Block 1202). Then the control  
22 circuitry 830 sends the modulated pulse train to the source assembly (40) to  
23 implement.

1       As the source assembly (40) generates spectral signals based on the  
2 modulated pulse train, the control circuitry 830 performs spectral de-convolution  
3 of the detected signals using a predefined numerical method for signal analysis  
4 that is based on the known temporal characteristics of the configured waveform.  
5 In particular, the detector assembly 800 detects the amplitude (intensity) of the  
6 detected signals (1220; Fig. 29A) from the sources (42) having the known  
7 modulated pulse train (Block 1204).

8       The control circuitry 830 mean centers the amplitude of the detected  
9 signals to create a mean centered signal (1230; Fig. 29B) (Block 1206) and then  
10 inverts values in the mean centered signal at discrete waveform specific  
11 locations (*i.e.*, times) of the known modulated pulse train to create an inverted  
12 signal (1240; Fig. 29C) (Block 1208). At this point, the control circuitry 830 sums  
13 the mean centered, inverted pulse train values to form a summed pulse train  
14 value (Block 1210). Then, the control circuitry 830 correlates this summed  
15 pulsed train value with the amplitude of the detected spectral signals so that  
16 subsequent analysis can be performed to determine characteristics of the sample  
17 fluid (Block 1212).

18       In this technique, the modulated pulse train requires a signal phase shift  
19 that is known or negligibly small relative to the modulation frequency used. In  
20 addition, the minimum sample period used in the analysis is preferably greater  
21 than  $1/\Delta f$ , where  $\Delta f$  is the frequency increment above the fundamental frequency  
22 ( $f_0$ ) used to illuminate the individual sources (42). Finally, no odd multiples of the  
23 frequency  $f$  (*i.e.* 1kHz and 3kHz) are used to pulse the sources (42).

1        This FFA mode produces similar results as the FFT mode discussed  
2        above. However, the FFA mode may be preferred because implementing this  
3        FFA mode in hardware is simpler compared to the hardware requirements for  
4        performing the analysis in the FFT mode discussed previously. In particular, the  
5        FFA mode reduces the computational load on the downhole control circuitry 830,  
6        reducing overall component size and power requirements. Compared to the FFT  
7        mode which requires  $2^n$  channels, the data processing in the FFA mode is faster  
8        because it only uses as many channels as needed. Any signal lag between  
9        acquisition and visualization can, therefore, be significantly reduced. In addition,  
10       the rate of data acquisition can be easily changed in conjunction with signal  
11       averaging for signal-to-noise ratio improvement.

12

### 13                    5. Asynchronous Hadamard Transform Encoding

14        In yet another operational mode, the control circuitry 830 operates the  
15        sources (42) using asynchronous Hadamard Transform encoding. In this mode,  
16        the control circuitry 830 configures the source assembly (40) to illuminate a  
17        unique sequence of a subset of sources (42) (e.g., LEDs) in a cyclic fashion with  
18        only one subset of sources (42) in operation at a given point in time. While  
19        operating in this mode, each source (42) may also be modulated at independent  
20        frequencies. In turn, the control circuitry 830 de-convolutes the signals detected  
21        from the measurement and reference detector units 810B/820B using Hadamard  
22        analysis to provide intensity information for later data processing.

1           In embodiments of the invention a detector assembly for downhole  
2   spectroscopy, comprises a reference unit having at least one reference detector  
3   and detecting first spectral signals across a spectral range of wavelengths from a  
4   reference channel of a source; a measurement unit having at least one  
5   measurement detector and detecting second spectral signals across the spectral  
6   range of wavelengths from a measurement channel of the source after  
7   interaction with a fluid sample; conversion circuitry communicatively coupled to  
8   the reference and measurement units and converting the first and second  
9   spectral signals into reference signals and measurement signals; and control  
10   circuitry communicatively coupled to the conversion circuitry and to the source of  
11   the spectral signals, the control circuitry processing the reference and  
12   measurements signals and configuring output of the spectral signals from the  
13   source based at least on the processed reference signals.

14           The reference and measurement detectors of the detector assembly are  
15   selected from the group consisting of a single-element photodiode, a multi-  
16   element photodiode, an avalanche photodiode, a photomultiplier tube, a micro-  
17   channel plate, a bolometer, and a thermopile.

18           The reference unit comprises a plurality of the reference detectors and a  
19   first router partitioning the reference channel into a plurality of first beams and  
20   routing each of the first beams to one or more of the reference detectors.

21           The first router comprises at least one optical element disposed in an  
22   optical path of the reference channel. The at least one optical element is selected

1 from the group consisting of a wavelength selection elements, a high-pass filter,  
2 a low-pass filter, and a dichroic element.

3 Each of the first beams comprises a unique spectral band different from  
4 the other first beams.

5 The at least one optical element comprises an adaptive optical element  
6 oscillatable between at least two orientations in the optical path of the reference  
7 channel, each of the at least two orientations corresponding to one of the first  
8 beams.

9 The measurement unit comprises a plurality of the measurement  
10 detectors, and a second router partitioning the measurement channel into a  
11 plurality of second beams and routing each of the second beams to one or more  
12 of the measurements detectors. The measurement detectors and the second  
13 beams correspond in arrangement to the reference detectors and the first  
14 beams.

15 To process the signals and configure the output, the control circuitry  
16 dynamically scales the measurement signal using the reference signal.

17 To process the signals and configure the output, the control circuitry  
18 deconvolves the measurement and reference signals based on a type of  
19 encoding used to encode the spectral signals output by the source. The control  
20 circuitry deconvolves the signals based on Raster Scanning encoding, Fast  
21 Fourier Transform encoding, other temporal encoding, Hadamard encoding, or  
22 other spectral encoding.

1        To process the signals and configure the output, the control circuitry  
2        temporally syncs the output of the source with at least the first spectral signals  
3        detected by the at least one reference detector to determine temporal  
4        characteristics of the source.

5        To process the signals and configure the output, the control circuitry  
6        scales the measurement signal with the reference signal to compensate for a  
7        fluctuation in the source or a change in an environmental condition.

8        To process the signals and configure the output, the control circuitry  
9        scales the output of the source to account for spectral changes caused by  
10       environmental conditions.

11       The control circuitry receives data of one or more environmental  
12       conditions from one or more external transducers, and the control circuitry scales  
13       the measurement signal, the reference signals, or both the measurement and  
14       reference signals based on spectral changes indicated by the one or more  
15       environmental conditions.

16       To process the signals and configure the output, the control circuitry  
17       configures a modulated pulse train for controlling illumination of the source. To  
18       configure the modulated pulse train, the control circuitry defines at least one  
19       temporal characteristic of the modulated pulse train, wherein the at least one  
20       temporal characteristic includes start time, pulse frequency, duty cycle, or pulse  
21       shape. To process the signals and configure the output, the control circuitry is  
22       configured to mean center values of the detected modulated pulse train; invert  
23       the mean centered values of the detected pulse trains at discrete temporal

1 locations; sum the inverted pulse train values; and correlate the summed pulsed  
2 train value with an amplitude of the spectral signals.

3 A downhole fluid analysis tool, comprises: a tool housing deployable  
4 downhole and having a flow passage for a fluid sample; and a fluid analysis  
5 device disposed in the tool housing relative to the flow passage, the fluid analysis  
6 device at least including: a source outputting spectral signals across a spectral  
7 range of wavelengths and partitioning the spectral signals into a reference  
8 channel and a measurement channel, a reference unit having at least one  
9 reference detector and detecting first spectral signals from the reference channel,  
10 a measurement unit having at least one measurement detector and detecting  
11 second spectral signals from the measurement channel, conversion circuitry  
12 communicatively coupled to the reference and measurement units and  
13 converting the first and second spectral signals into reference signals and  
14 measurement signals, and control circuitry communicatively coupled to the  
15 conversion circuitry and to the source of the spectral signals, the control circuitry  
16 processing the reference and measurements signals and configuring output of  
17 the spectral signals from the source based at least on the processed reference  
18 signals.

19 A downhole spectroscopy method, comprises: detecting first spectral  
20 signals across a spectral range of wavelengths from a reference channel output  
21 by a source using at least one reference detector; detecting second spectral  
22 signals across the spectral range of wavelengths from a measurement channel  
23 output by the source after interaction with a fluid sample using at least one

1 measurement detector; digitizing the first and second spectral signals into  
2 reference and measurement signals; processing the reference and measurement  
3 signals; and configuring output of the spectral signals from the source based at  
4 least on the processed reference signals.

5 The detectors are selected from the group consisting of single-element  
6 photodiodes, multi-element photodiodes, avalanche photodiodes, photomultiplier  
7 tubes, micro-channel plates, bolometers, and thermopiles.

8 The at least one reference detector comprises a plurality of reference  
9 detectors, and wherein the method comprises partitioning the reference channel  
10 into a plurality of first beams and routing each of the first beams to one of the  
11 reference detectors. Partitioning the reference channel comprises disposing at  
12 least one optical element in an optical path of the reference channel and  
13 partitioning the reference channel into at least two beams with the at least one  
14 optical element.

15 The at least one optical element is selected from a high-pass filter, a low-  
16 pass filter, and a dichroic element.

17 Each of the first beams comprises a unique spectral band different from  
18 the other first beams.

19 The at least one optical element comprises an adaptive optical element  
20 oscillatable between at least two orientations in the optical path of the reference  
21 channel, each of the at least two orientations corresponding to one of the first  
22 beams.

1           The at least one measurement detector comprises a plurality of  
2 measurement detectors, and wherein the method comprises partitioning the  
3 measurement channel into a plurality of second beams and routing each of the  
4 second beams to one of the measurements detectors. The measurement  
5 detectors and the second beams correspond in arrangement to the reference  
6 detectors and the first beams.

7           Processing the signals and configuring the output comprises dynamically  
8 scaling the measurement signal with the reference signal. Dynamically scaling  
9 the measurement signal with the reference signal comprises compensating for a  
10 fluctuation in the source or a change in an environmental condition.

11          Processing the signals and configuring the output comprises deconvolving  
12 the signals based on a type of encoding used to encode the spectral signals  
13 output by the source. The encoding used includes Raster Scanning encoding,  
14 Fast Fourier Transform encoding, other temporal encoding, Hadamard encoding,  
15 or other spectral encoding.

16          Processing the signals and configuring the output comprises temporally  
17 syncing the spectral signals output by the source with the spectral signals at least  
18 detected by the at least one reference detector.

19          Processing the signals and configuring the output comprises accounting  
20 for spectral changes caused by environmental conditions by scaling the spectral  
21 signals output by the source.

22          Processing the signals and configuring the output comprises: receiving  
23 data of one or more environmental conditions from one or more external

1 transducers, and scaling the measurement signal, the reference signals, or both  
2 the measurement and reference signals based on spectral changes indicated by  
3 the one or more environmental conditions.

4 Processing the signals and configuring the output comprises configuring a  
5 modulated pulse train for illuminating the source. Configuring the modulated  
6 pulse train comprises defining at least one temporal characteristic of the pulse  
7 train, wherein the at least one temporal characteristic includes start time, pulse  
8 frequency, duty cycle, or pulse shape.

9 Processing the signals and configuring the output comprises: mean  
10 centering values of the detected pulse train; inverting the mean centered values  
11 of the detected pulse trains at discrete temporal locations; summing the inverted  
12 pulse train values; and correlating the summed pulsed train value with an  
13 amplitude of the spectral signal from the source.

14 A downhole fluid analysis method, comprises: deploying a tool downhole,  
15 the tool having a flow passage for a fluid sample; and analyzing the fluid sample  
16 by operating a source to generate spectral signals across a spectral range of  
17 wavelengths in a reference channel and a measurement channel, detecting the  
18 spectral signals of the reference channel using at least one reference detector,  
19 detecting the spectral signals from the measurement channel after interaction  
20 with the fluid sample using at least one measurement detector, digitizing the  
21 spectral signals sensed by the at least one reference detector into reference  
22 signals; digitizing the spectral signals sensed by the at least one measurement  
23 detectors into measurement signals, processing the reference and measurement

1 signals, and controlling output of the spectral signals from the source based at  
2 least on the processed reference signals.

3 A downhole spectroscopy signal processing method, comprises: defining  
4 one or more temporal characteristics of a modulated pulse train used for  
5 operating a source of spectral signals across a spectral range of wavelengths;  
6 detecting the spectral signals from the source; mean centering values of the  
7 modulated pulse train in the detected spectral signals; inverting the mean  
8 centered values of the modulated pulse train at discrete temporal locations;  
9 summing the inverted pulse train values; and correlating the summed pulsed  
10 train value with an amplitude of the detected spectral signals.

11 Although the disclosure refers to electromagnetic radiation using the terms  
12 "optical signals," "light," "emissions," and the like, these references may actually  
13 be intended to include wavelengths outside the bounds of visible light. Further,  
14 while the discussion herein focused on the wavelength ranges of the ultraviolet,  
15 visible, and near-infrared regions of the electromagnetic spectrum being used, it  
16 will be appreciated that the disclosed device can be configured to manipulate all  
17 wavelengths of electromagnetic radiation. As used herein, the term  
18 "spectroscopy" refers to the production and investigation of spectra and the term  
19 "spectroscopic devices" includes instruments for forming and examining spectra  
20 especially in the visible region of the electromagnetic spectrum including, but is  
21 not limited to, a spectrometer, among other instruments for spectral analysis of  
22 downhole fluids.

1           The foregoing description of preferred and other embodiments is not  
2 intended to limit or restrict the scope or applicability of the inventive concepts  
3 conceived of by the Applicants. Although several detection/signal processing  
4 modes for the detection assembly 800 have been discussed above, for example,  
5 it will be appreciated that the assembly 800 can be operated based on other  
6 modes of operation known to those skilled in the art.

7           In exchange for disclosing the inventive concepts contained herein, the  
8 Applicants desire all patent rights afforded by the appended claims. Therefore, it  
9 is intended that the appended claims include all modifications and alterations to  
10 the full extent that they come within the scope of the following claims or the  
11 equivalents thereof.

12

1   **WHAT IS CLAIMED IS**

2

3                   1.     A source assembly for downhole spectroscopy, comprising:  
4                   a plurality of individual light emitting diode (LED) sources deployed  
5     downhole in the source assembly and generating optical signals across a  
6     spectral range of wavelengths;  
7                   a routing assembly deployed downhole in the source assembly, the  
8     routing assembly spectrally filtering the generated signals of the LED sources,  
9     concurrently combining the spectrally filtered signals through free space into a  
10    combined signal, and concurrently routing the combined signal through free  
11    space into a reference channel and one or more measurement channels; and  
12                  control circuitry deployed downhole in the source assembly, the  
13    control circuitry electrically coupled to the LED sources and operable to  
14    electronically modulate each of the LED sources at an independent frequency.

15

16                  2.     The assembly of claim 1, wherein the LED sources are  
17    selected from the group consisting of light emitting diodes (LEDs), and super-  
18    luminescent light emitting diodes (SLEDs).

19

20                  3.     The assembly of claims 1 or 2, wherein the LED sources  
21    provide a continuous spectral distribution over a broad spectral range of  
22    wavelengths.

23

1                   4.     The assembly of claims 1 or 2, wherein the LED sources  
2 provide a non-continuous spectral distribution of two or more spectrally  
3 continuous regions interposed by at least one spectrally dark region over a broad  
4 spectral range of wavelengths.

5

6                   5.     The assembly of any one of claims 1 to 3, wherein the  
7 routing assembly comprises one or more filters spectrally filtering the optical  
8 signals from one or more of the LED sources.

9

10                  6.     The assembly of any one of claims 1 to 4, wherein the  
11 routing assembly comprises one or more optical elements spatially shaping the  
12 optical signals from one or more of the LED sources.

13

14                  7.     The assembly of any one of claims 1 to 6, wherein to  
15 electronically modulate each of the LED sources, the control circuitry turns each  
16 of the individual LED sources on and off or electronically modulates each LED  
17 source about a mean amplitude.

18

19                  8.     The assembly of any one of claims 1 to 7, wherein to  
20 electronically modulate each of the LED sources, the control circuitry  
21 electronically modulates two or more of the individual LED sources at a unique  
22 frequency different from one another.

23

24

1                   9.     The assembly of any one of claims 1 to 7, wherein to  
2 electronically modulate each of the LED sources, the control circuitry  
3 electronically modulates two or more of the individual LED sources at the same  
4 frequency.

5

6                   10.    The assembly of any one of claims 1 to 9, wherein the  
7 routing assembly comprises:

8                   one or more couplers optically coupled to each of the LED sources;

9     and

10                  a router coupled to the one or more couplers and routing the  
11 optically combined signals from the one or more couplers into the reference  
12 channel and the one or more measurement channels.

13

14                  11.    The assembly of claim 10, wherein the one or more couplers  
15 comprise a segmented mirror having the LED sources arranged thereabout, the  
16 segmented mirror imaging optical signals from each of the LED sources into the  
17 combined signal that is optically coupled to the router.

18

19                  12.    The assembly of claim 10, wherein the one or more couplers  
20 comprises a series of filters disposed adjacent the LED sources and at least one  
21 optic element imaging at least a portion of the optical signals from each of the  
22 adjacent LED sources to the combined signal optically coupled to the router.

23

24                  13.    The assembly of any one of claims 1 to 12, wherein the  
25 routing assembly comprises a micro-optical bench.

1                   14.    The assembly of any one of claims 1 to 12, wherein the  
2   routing assembly comprises a splitter fractionally splitting the combined signal  
3   into the reference and the one or more measurement channels.  
4

5                   15.    The assembly of any one of claims 1 to 12, wherein the  
6   routing assembly comprises an adaptive optical element optically coupled to the  
7   combined signal and oscillating between a first orientation and one or more  
8   second orientations, the adaptive optical element in the first orientation  
9   producing the reference channel, the adaptive optical element in the one or more  
10   second orientations producing the one or more measurement channels.  
11

12                  16.    The assembly of any one of claims 1 to 12, wherein the LED  
13   sources are spatially configured on an array topology arranged in one or more  
14   dimensions, and wherein the routing assembly comprises a grating optically  
15   coupled to the spatially configured LED sources and combining the signals from  
16   the LED sources into a at least one optical beam.  
17

18                  17.    The assembly of claim 16, wherein the routing assembly  
19   images a first portion of the at least one optical beam for the reference channel  
20   and images one or more second portions of the at least one optical beam for the  
21   one or more measurement channels.  
22  
23

1                   18.    The assembly of claim 16, wherein the routing assembly  
2   comprises a router optically coupled to the at least one optical beam and routing  
3   the at least one optical beam into the reference channel and the one or more  
4   measurement channels.

5  
6                   19.    The assembly of claim 16, wherein the at least one optical  
7   beam comprises first and second optical beams, the first optical beam generated  
8   using a first order reflection of the grating, the second optical beam generated  
9   using a second order reflection of the grating, the one or more measurement  
10   channels imaged using the first order reflection, the reference channel imaged  
11   using the second order reflection.

12  
13                  20.    The assembly of any one of claims 1 to 19, wherein the  
14   control circuitry receives input indicative of measured energy of the reference  
15   channel and controls an amplitude of the LED sources based on the input.

16  
17                  21.    The assembly of any one of claims 1 to 20, wherein the  
18   control circuitry electronically modulates the LED sources in a synchronous  
19   encoding mode in which the control circuitry operates each of two or more LED  
20   sources simultaneously using an independent frequency to generate optical  
21   signals, the synchronous encoding mode enabling Fast-Fourier Transform  
22   analysis of the measurement and reference channels.

23  
24

1                   22. The assembly of any one of claims 1 to 20, wherein the  
2 control circuitry electronically modulates the LED sources in a synchronous  
3 encoding mode in which the control circuitry operates the LED sources  
4 simultaneously using fixed frequency increments, the synchronous encoding  
5 mode enabling deconvolution of the measurement and reference channels  
6 based on predefined temporal characteristics of the fixed frequency increments.

7

8                   23. The assembly of any one of claims 1 to 20, wherein the  
9 control circuitry electronically modulates the LED sources in an asynchronous  
10 encoding mode in which the control circuitry operates each of two or more LED  
11 sources in a serial fashion with only one of the LED sources in operation at any  
12 point in time, the asynchronous encoding mode enabling raster scanning  
13 analysis of the measurement and reference channels.

14

15                   24. The assembly of any one of claims 1 to 20, wherein the  
16 control circuitry electronically modulates the LED sources in an asynchronous  
17 encoding mode in which the control circuitry operates a unique sequence of  
18 subsets of the LED sources in a cyclic fashion with only one of the subsets of the  
19 LED sources in operation at a given point in time, the asynchronous encoding  
20 mode enabling Hadamard Transform analysis of the measurement and  
21 reference channels.

22

23

1                   25.    A downhole fluid analysis tool, comprising:  
2                   a tool housing deployable downhole and having a flow passage for  
3   a fluid sample; and  
4                   a fluid analysis device disposed in the tool housing relative to the  
5   flow passage, the fluid analysis device at least including—  
6                   a plurality of individual light emitting diode (LED) sources  
7   generating optical signals across a spectral range of wavelengths,  
8                   a routing assembly spectrally filtering the generated signals,  
9   concurrently combining the spectrally filtered signals of each of the LED  
10   sources through free space into a combined signal and concurrently  
11   routing the combined signal through free space into a reference channel  
12   and one or more measurement channels, and  
13                   control circuitry electrically coupled to the LED sources and  
14   operable to electronically modulate each of the LED sources at an  
15   independent frequency.

16

17

1                   26.    A downhole fluid analysis method, comprising:  
2                   deploying a fluid analysis device downhole;  
3                   obtaining a fluid sample downhole;  
4                   generating a plurality of optical signals across a spectrum of  
5 wavelengths by electronically modulating each of a plurality of light emitting  
6 diode (LED) sources at an independent frequency;  
7                   spectrally filtering the generated signals from one or more of the  
8 LED sources;  
9                   concurrently combining the spectrally filtered signals through free  
10 space into a combined signal; and  
11                  routing the combined signal concurrently through free space into  
12 one or more measurement channels for interacting with the fluid sample and into  
13 a reference channel for dynamically scaling the measurement channel.

14  
15                  27.    The method of claim 26, wherein spectrally filtering the  
16 generated signals from one or more of the LED sources comprises concurrently  
17 routing the spectrally filtered signals from one or more of the LED sources using  
18 an arrangement of optical elements.

19  
20                  28.    The method of claim 26 or 24, wherein modulating each of  
21 the LED sources comprises turning each of the individual LED sources on and  
22 off.

23                  29.    The method of any one of claims 26 to 28, wherein  
24 modulating each of the LED sources comprises modulating each of the individual  
25 LED sources about a mean amplitude.

1           30. The method of any one of claims 26 to 28, wherein  
2 modulating each of the LED sources comprises modulating two or more of the  
3 individual LED sources at the same frequency.

4  
5           31. The method of any one of claims 26 to 28, wherein  
6 modulating each of the LED sources comprises modulating two or more of the  
7 individual LED sources at unique frequencies different from one another.

8  
9           32. The method of any one of claims 26 to 31, wherein  
10 combining the spectrally filtered signals into a combined signal comprises  
11 imaging each of the individual LED sources into an optical coupler.

12  
13           33. The method of any one of claims 26 to 31, wherein routing  
14 the combined signal comprises fractionally splitting the combined signal into the  
15 reference and measurement channels.

16  
17           34. The method of any one of claims 26 to 31, wherein routing  
18 the combined signal concurrently into one or more measurement channels  
19 comprises oscillating the combined signal between a first orientation producing  
20 the reference channel and a second orientation producing the measurement  
21 channel, the first and second orientations routing the combined signal  
22 concurrently by routing the combined signal in parallel.

23

24

1                   35.    The method of any one of claims 26 to 33, wherein the acts  
2 of generating, combining, and routing comprise:

3                   spatially configuring the individual LED sources in one or more  
4 dimensions;

5                   combining the optical signals from the spatially configured sources  
6 using a grating; and

7                   routing the combined signal into the measurement and reference  
8 channels.

9

10                  36.    The method of claim 35, wherein routing the combined  
11 signal comprises imaging a first portion of the combined signal into the reference  
12 channel and imaging a second portion of the combined signal into the one or  
13 more measurement channels.

14

15                  37.    The method of claim 35, wherein the acts of routing  
16 comprises:

17                  routing a first order reflection of the grating into the one or more  
18 measurement channels; and

19                  routing a second order reflection of the grating into the reference  
20 channel.

21

22                  38.    The method of any one of claims 26 to 37, wherein  
23 modulating each of a plurality of LED sources is controlled based on measured  
24 energy of the reference channel.

25

1           39. The method of any one of claims 26 to 37, wherein  
2 modulating each of a plurality of LED sources comprises synchronously  
3 encoding the LED sources by simultaneously operating each of two or more of  
4 the LED sources and modulating each with an independent frequency.

5

6           40. The method of any one of claims 26 to 37, wherein  
7 modulating each of a plurality of LED sources comprises synchronously  
8 encoding the LED sources by operating the LED sources simultaneously using  
9 fixed frequency increments.

10

11           41. The method of any one of claims 26 to 37, wherein  
12 modulating each of a plurality of LED sources comprises asynchronously  
13 encoding the LED sources by operating each of two or more of the sources in a  
14 serial fashion with only one of the LED sources in operation at any point in time.

15           42. The method of any one of claims 26 to 37, wherein  
16 modulating each of a plurality of LED sources comprises asynchronously  
17 encoding the LED sources by operating a unique sequence of subsets of the  
18 sources in a cyclic fashion with only one of the subsets of the LED sources in  
19 operation at a given point in time.

20

21

1                   43.    A source assembly for downhole spectroscopy, comprising:  
2                   a plurality of individual sources generating optical signals across a  
3   spectral range of wavelengths, the sources being spatially configured on an  
4   array topology arranged in one or more dimensions;  
5                   a routing assembly combining the generated signals of the sources  
6   into a combined signal and routing the combined signal into a reference channel  
7   and one or more measurement channels,  
8                   the routing assembly comprising a grating optically coupled  
9   to the spatially configured sources and combining the signals from the  
10   sources into a common optical beam, and  
11                   the grating comprising first and second optical beams, the  
12   first optical beam generated using a first order reflection of the grating, the  
13   second optical beam generated using a second order reflection of the  
14   grating, the one or more measurement channels imaged using the first  
15   order reflection, the reference channel imaged using the second order  
16   reflection; and  
17                   control circuitry electrically coupled to the sources and operable to  
18   electronically modulate each of the sources at an independent frequency.

19  
20                   44.    The assembly of claim 43, wherein the control circuitry  
21   receives input indicative of measured energy of the reference channel and  
22   controls an amplitude of the sources based on the input.

23  
24                   45.    The assembly of claim 43 or 44, wherein the control circuitry  
25   electronically modulates the sources in a synchronous encoding mode in which

1 the control circuitry operates each of two or more sources simultaneously using  
2 an independent frequency to generate optical signals, the synchronous encoding  
3 mode enabling Fast-Fourier Transform analysis of the measurement and  
4 reference channels.

5

6 46. The assembly of claim 43 or 44, wherein the control circuitry  
7 electronically modulates the sources in a synchronous encoding mode in which  
8 the control circuitry operates the sources simultaneously using fixed frequency  
9 increments, the synchronous encoding mode enabling deconvolution of the  
10 measurement and reference channels based on predefined temporal  
11 characteristics of the fixed frequency increments.

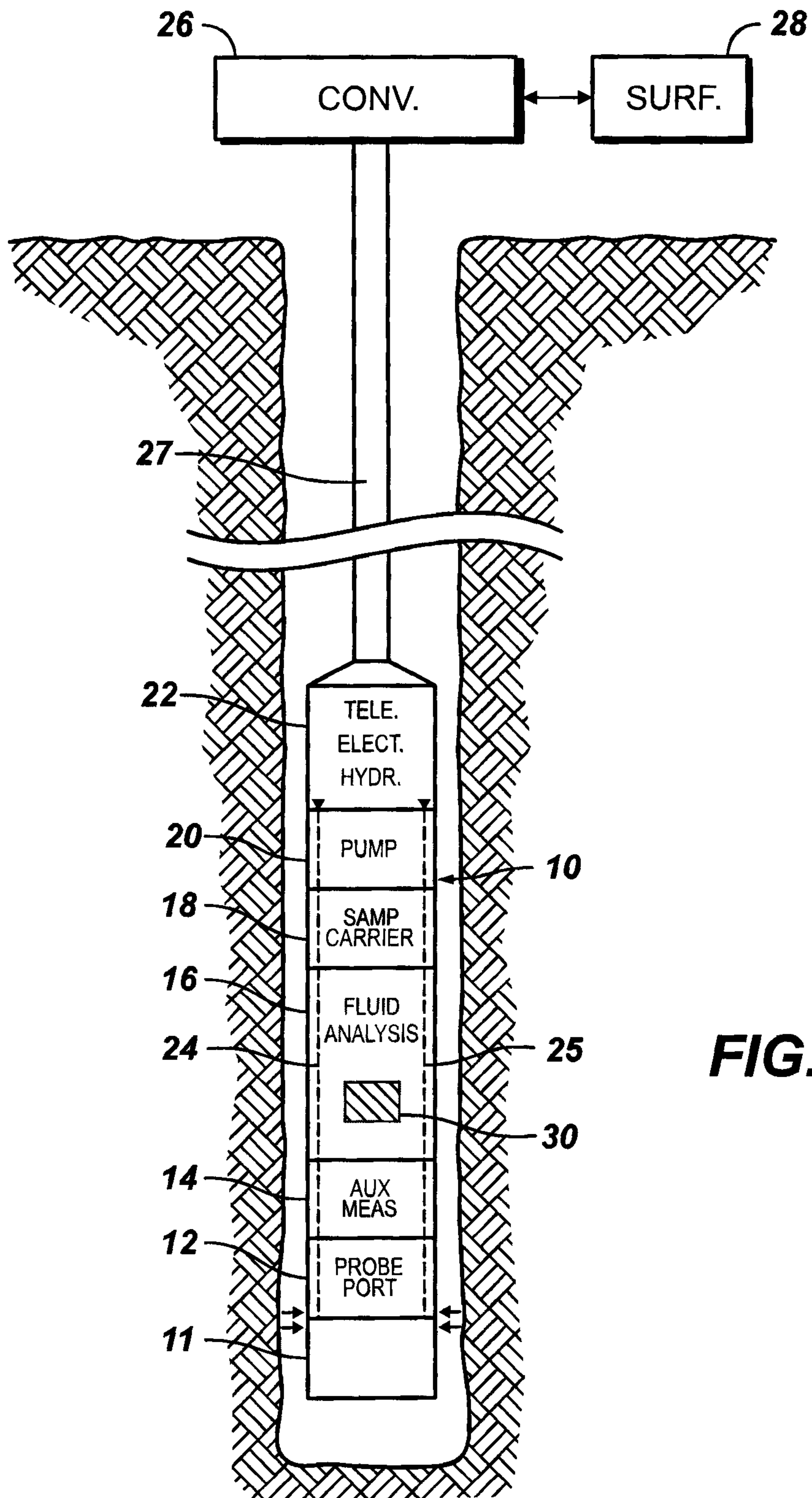
12

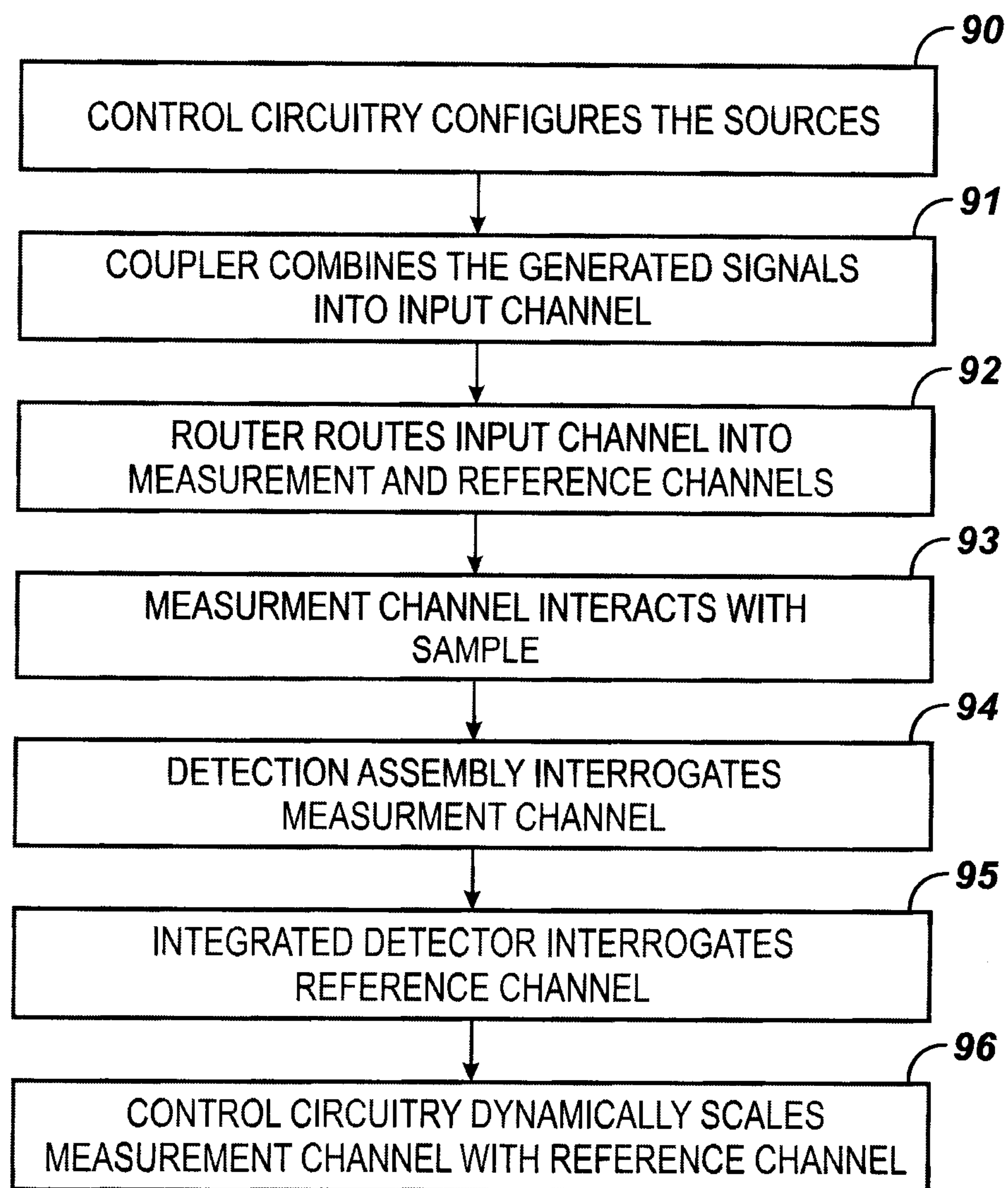
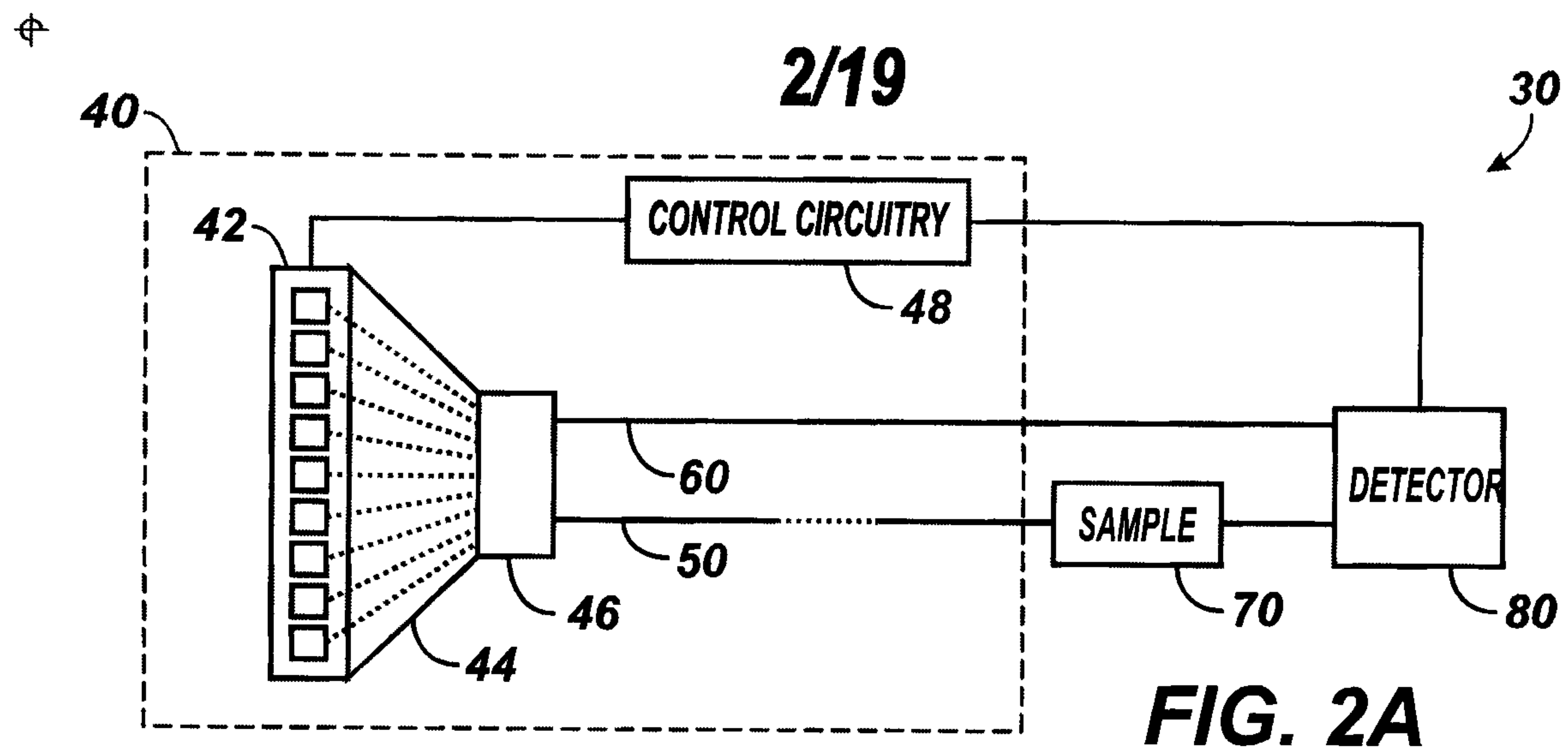
13 47. The assembly of claim 43 or 44, wherein the control circuitry  
14 electronically modulates the sources in an asynchronous encoding mode in  
15 which the control circuitry operates each of two or more sources in a serial  
16 fashion with only one of the sources in operation at any point in time, the  
17 asynchronous encoding mode enabling raster scanning analysis of the  
18 measurement and reference channels.

19

20 48. The assembly of claim 43 or 44, wherein the control circuitry  
21 electronically modulates the sources in an asynchronous encoding mode in  
22 which the control circuitry operates a unique sequence of subsets of the sources  
23 in a cyclic fashion with only one of the subsets of the sources in operation at a  
24 given point in time, the asynchronous encoding mode enabling Hadamard  
25 Transform analysis of the measurement and reference channels.

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**FIG. 1**



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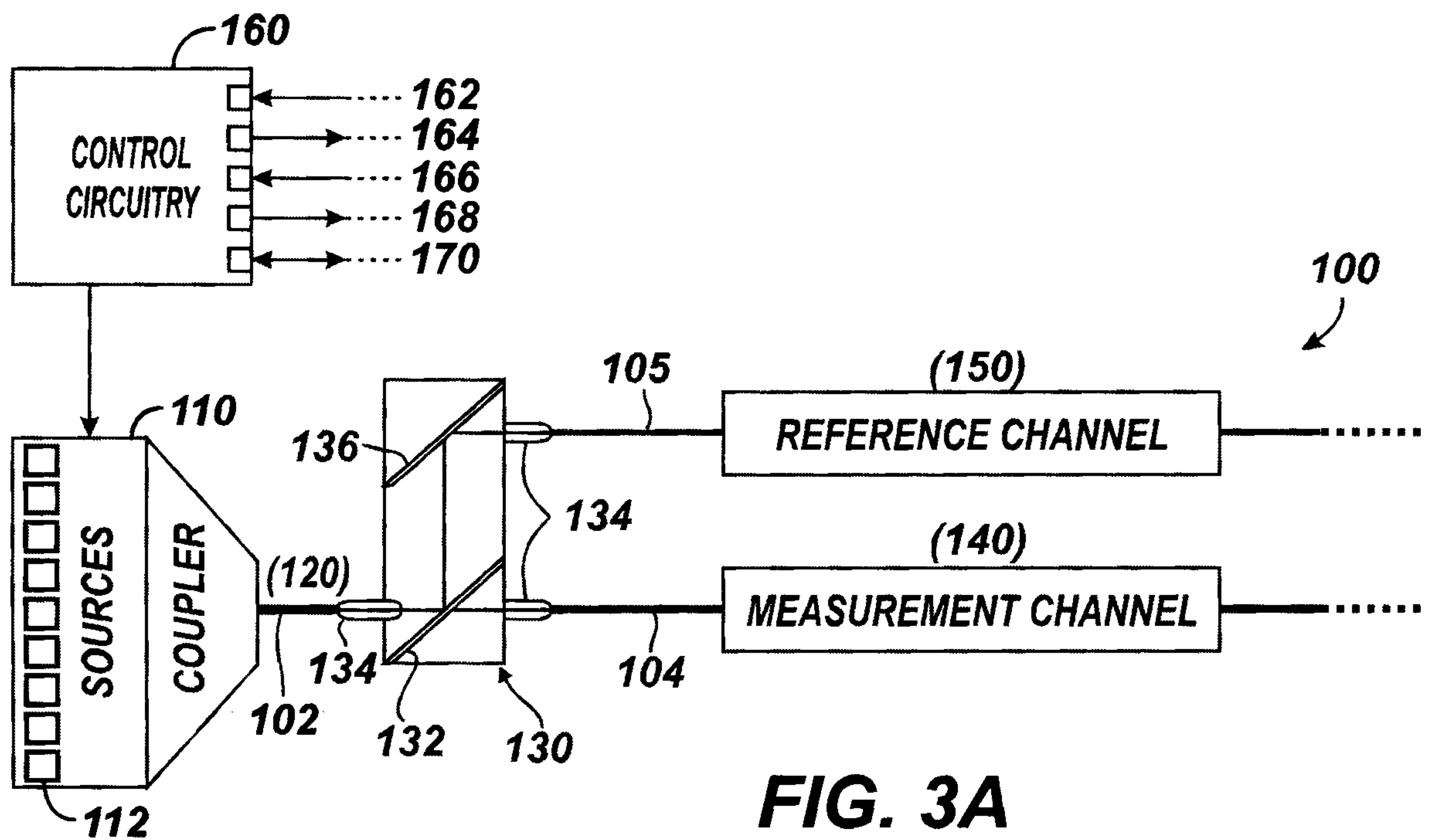


FIG. 3A

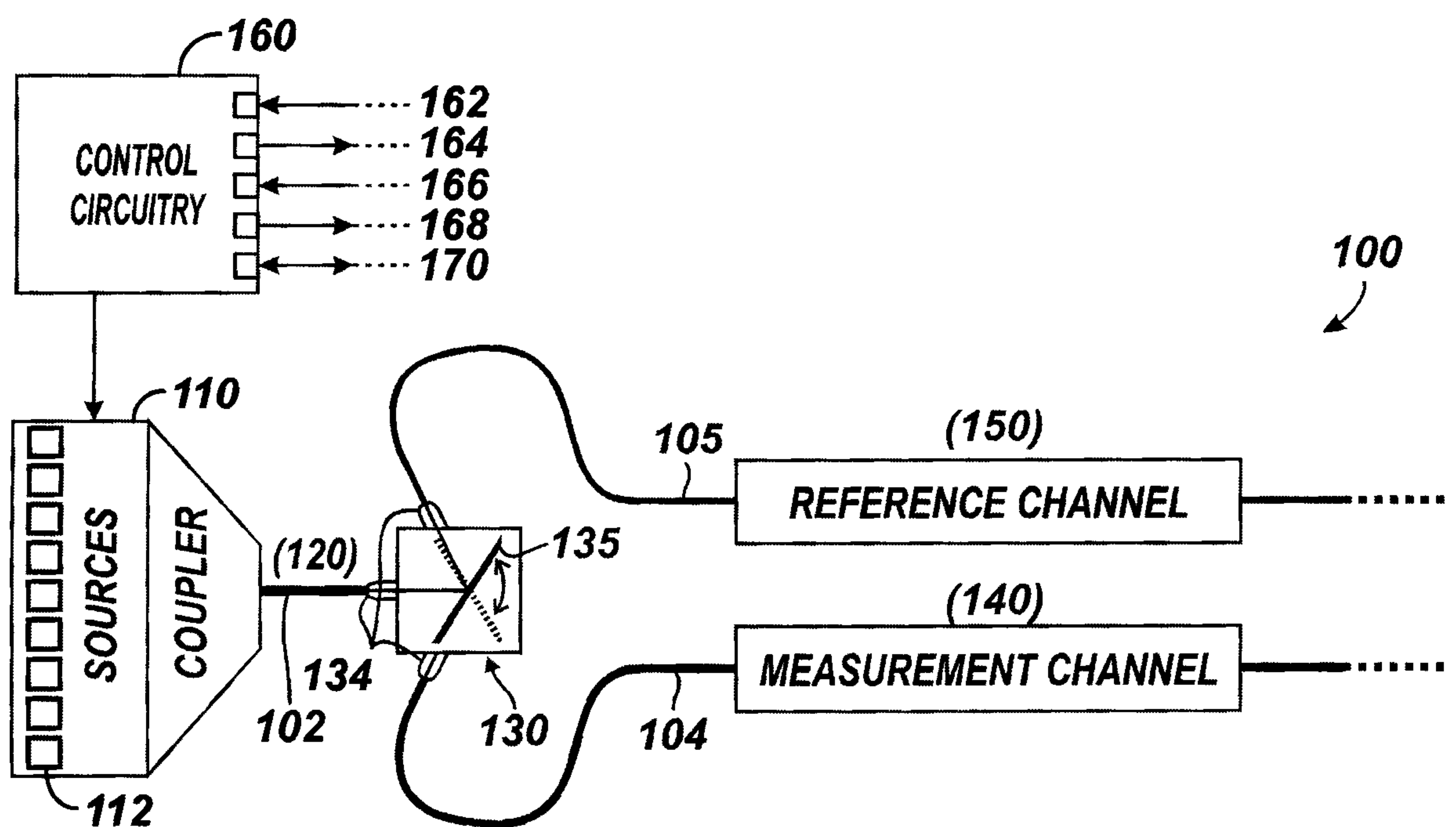
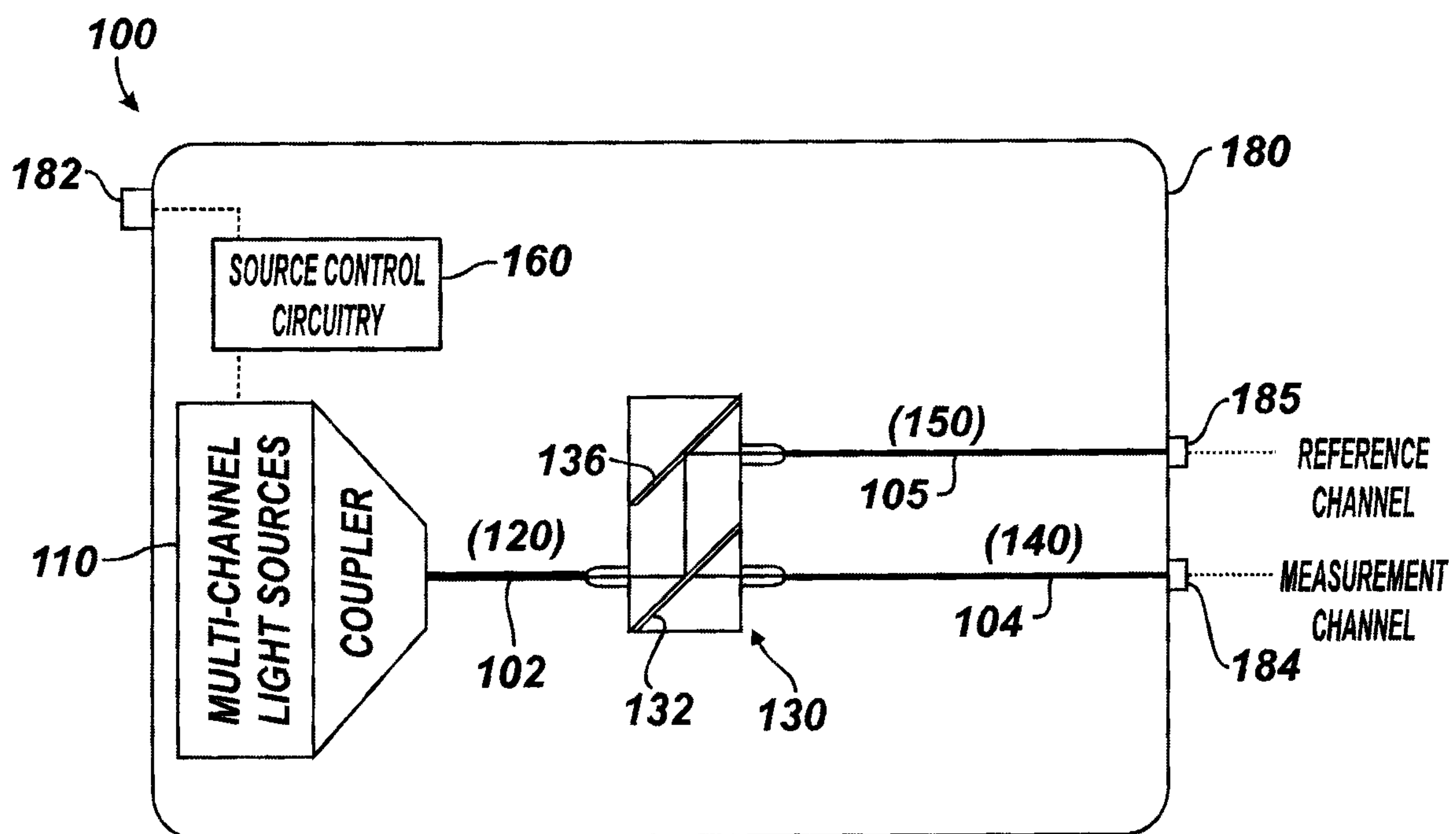
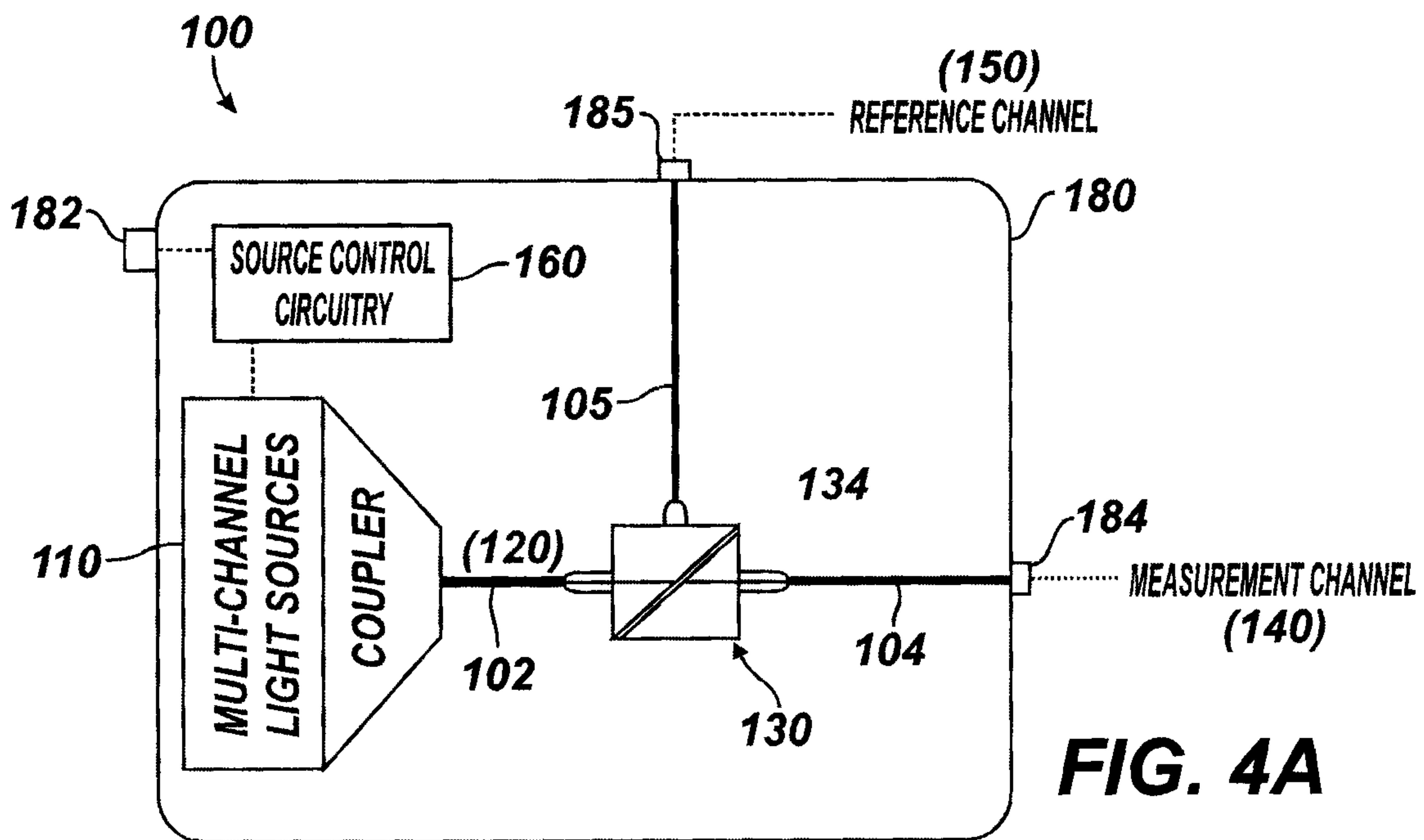


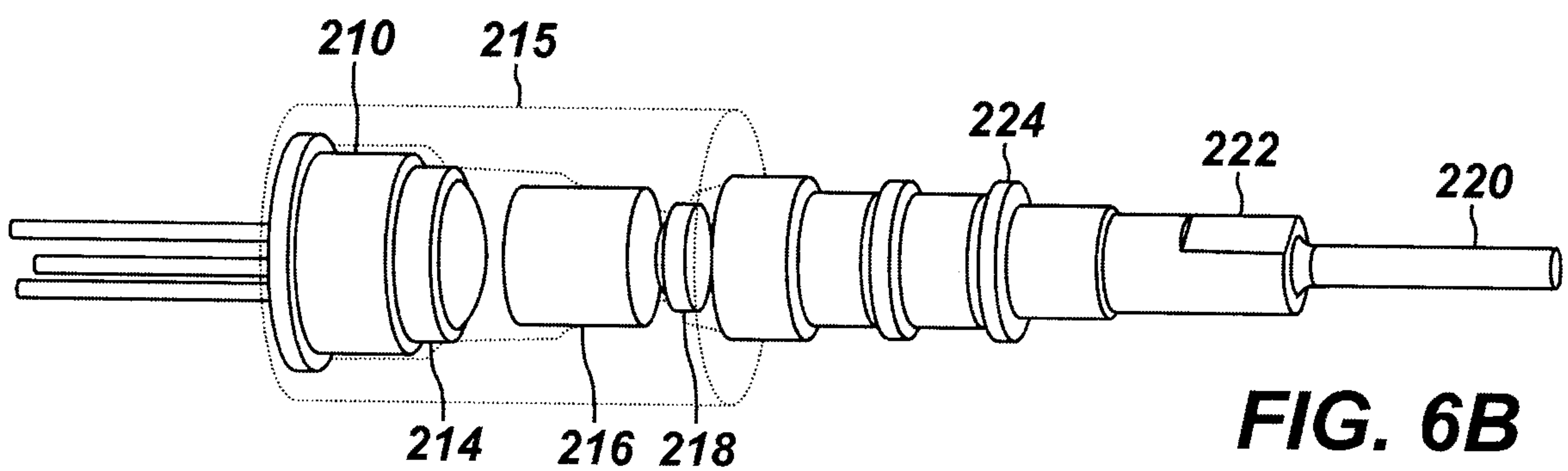
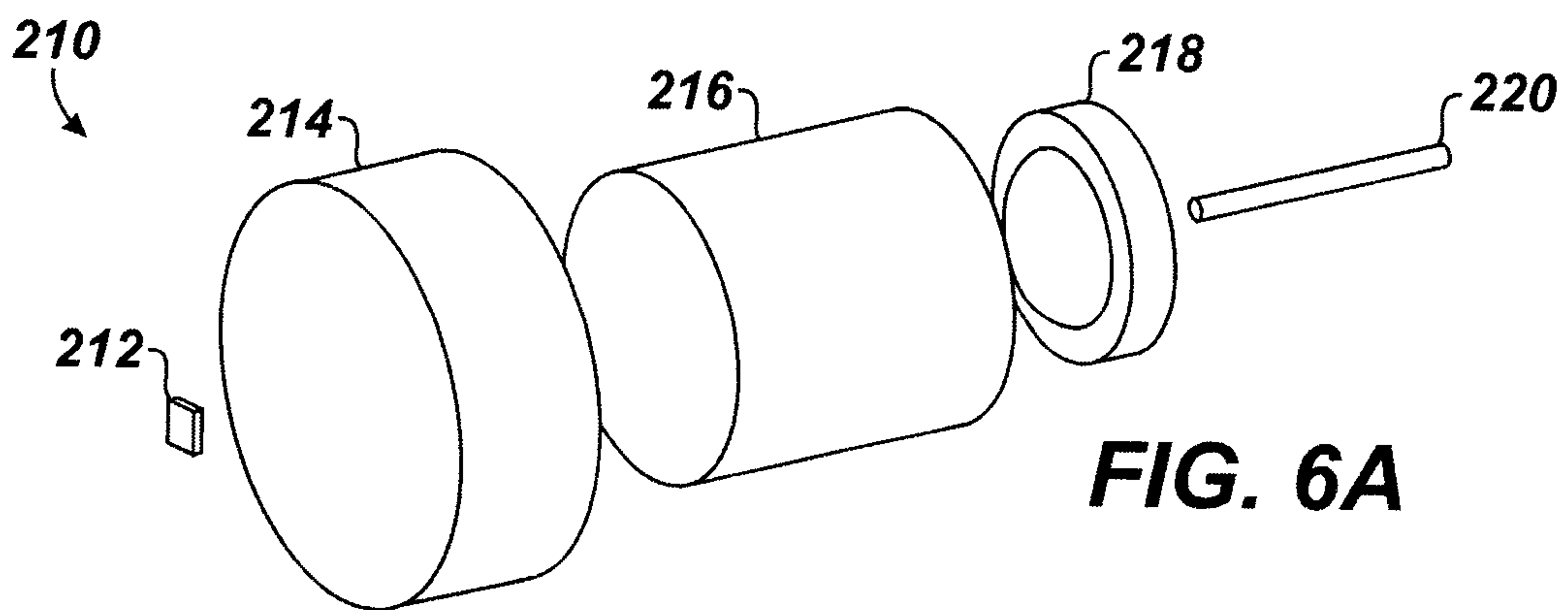
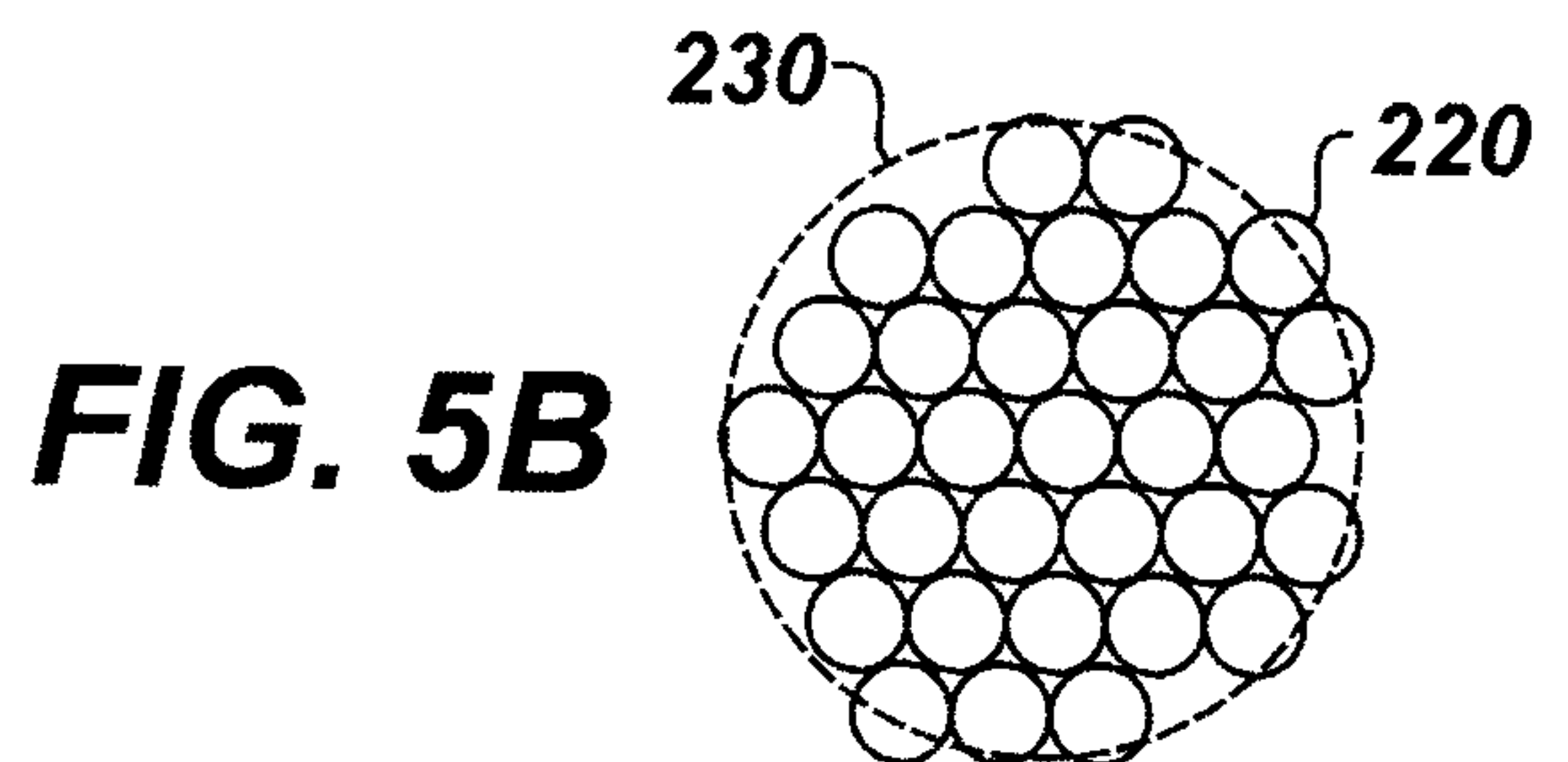
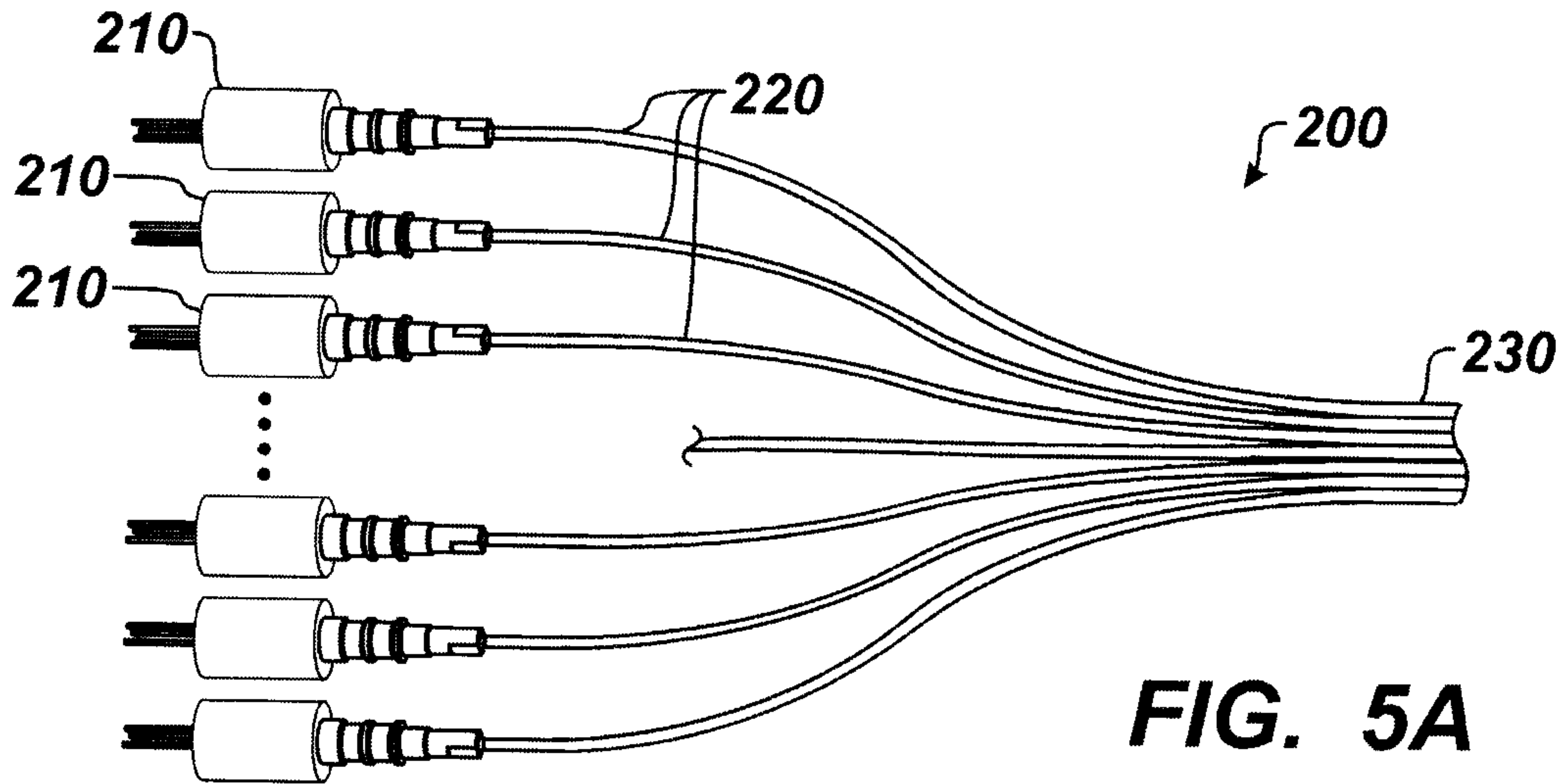
FIG. 3B

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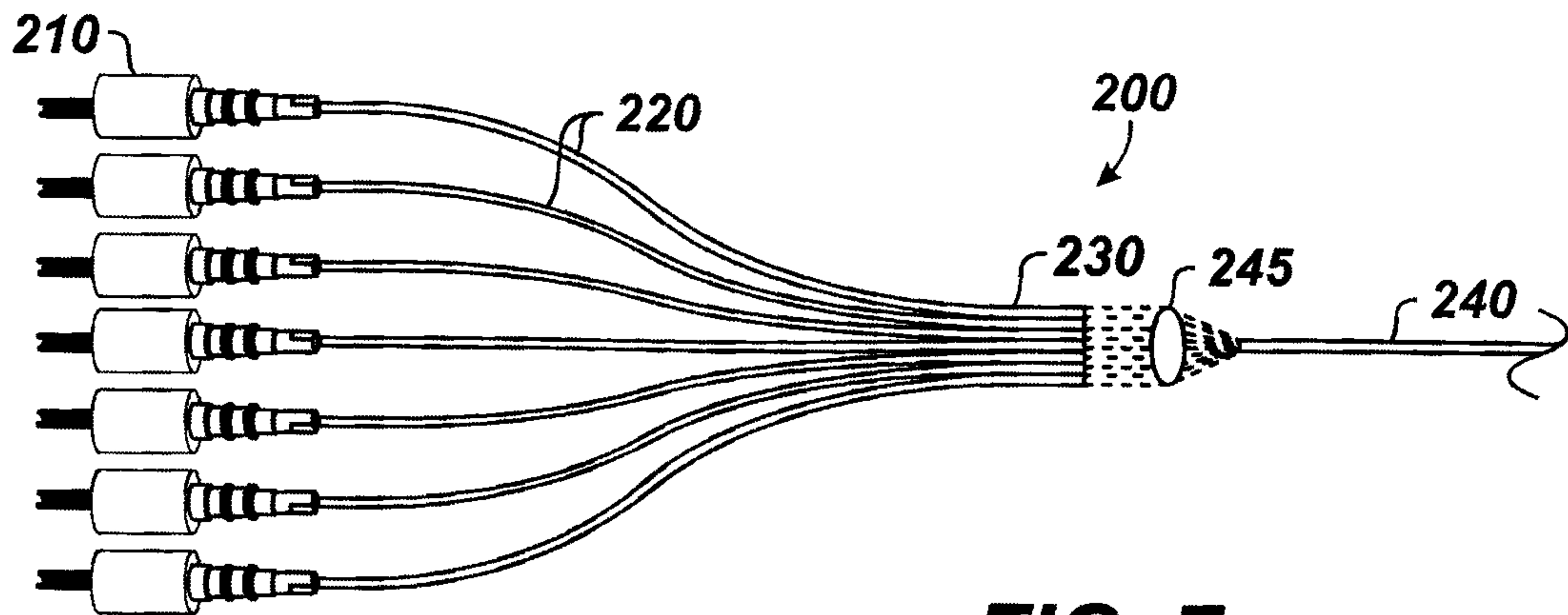
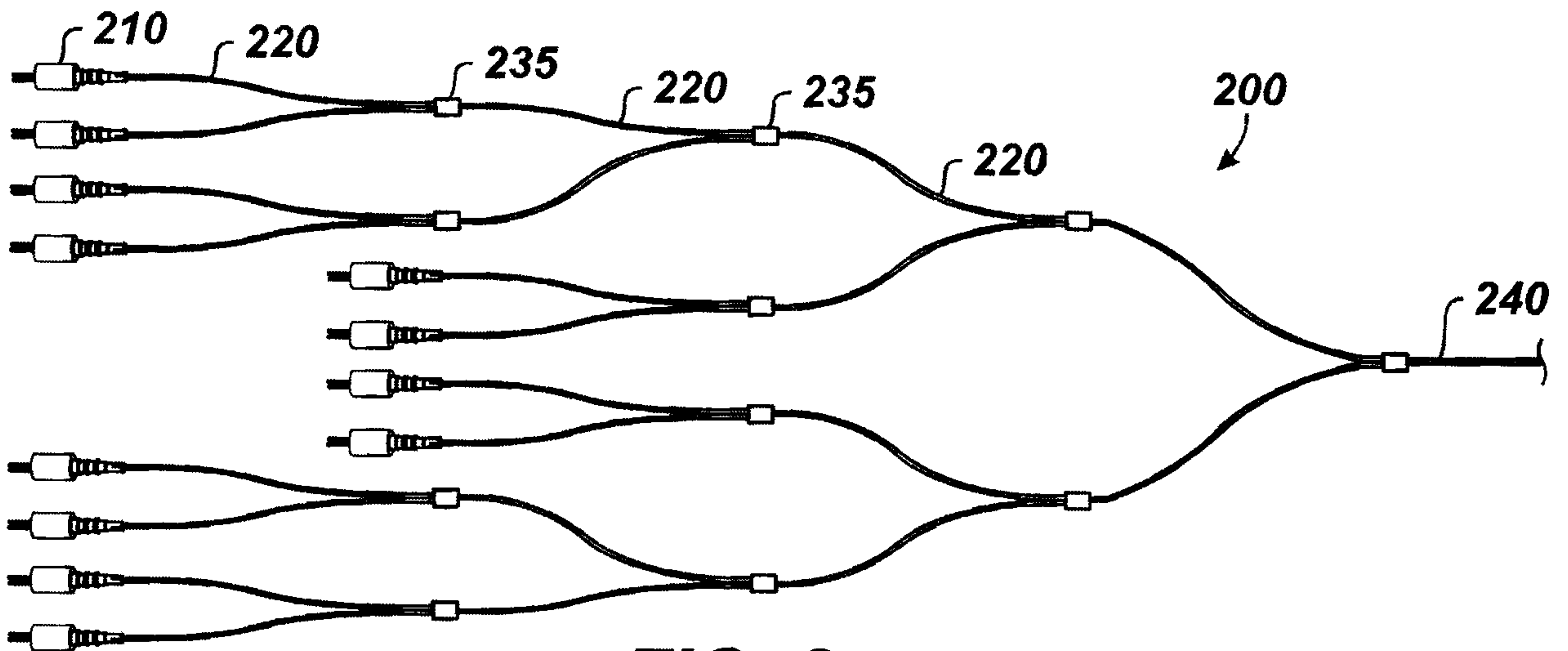
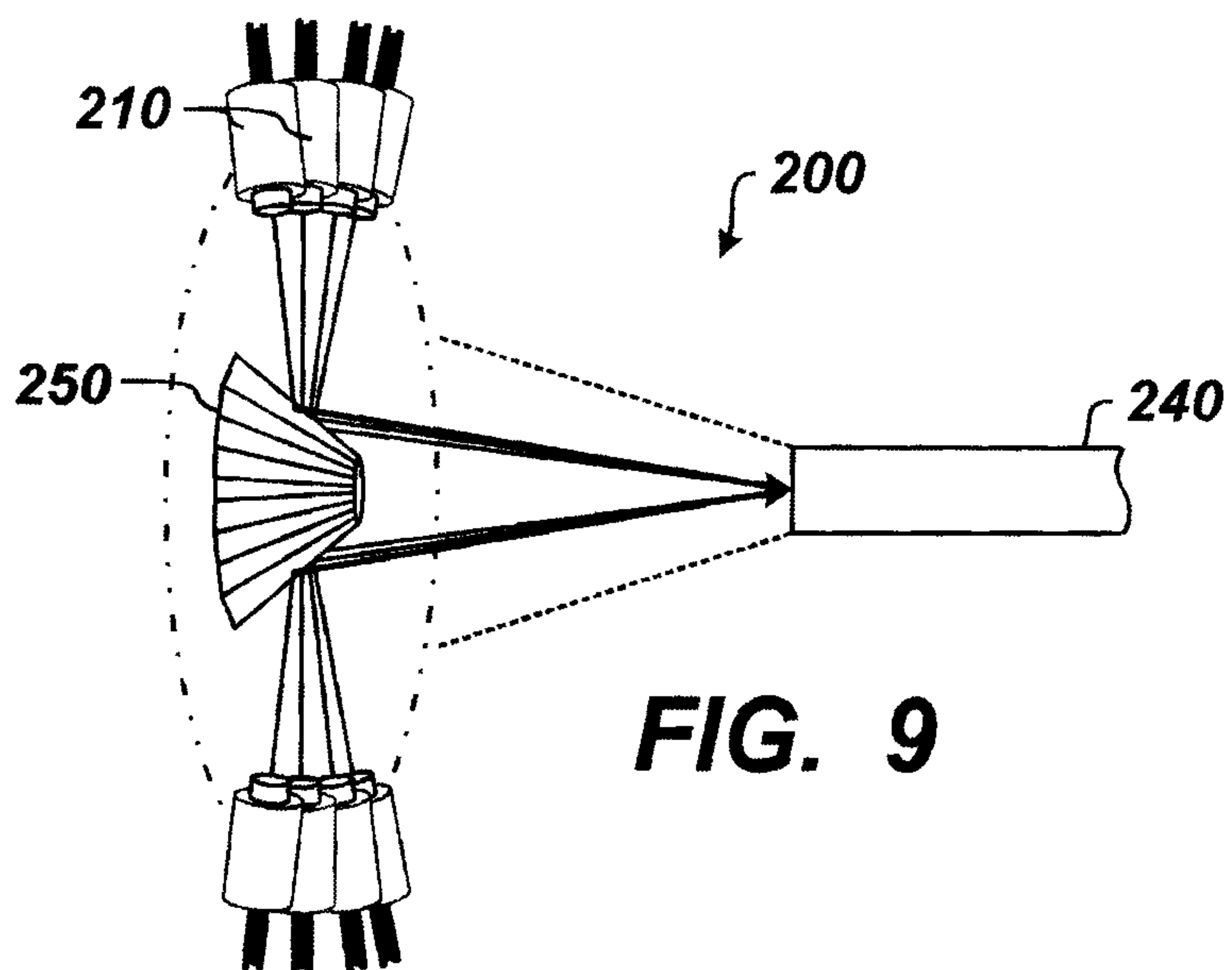
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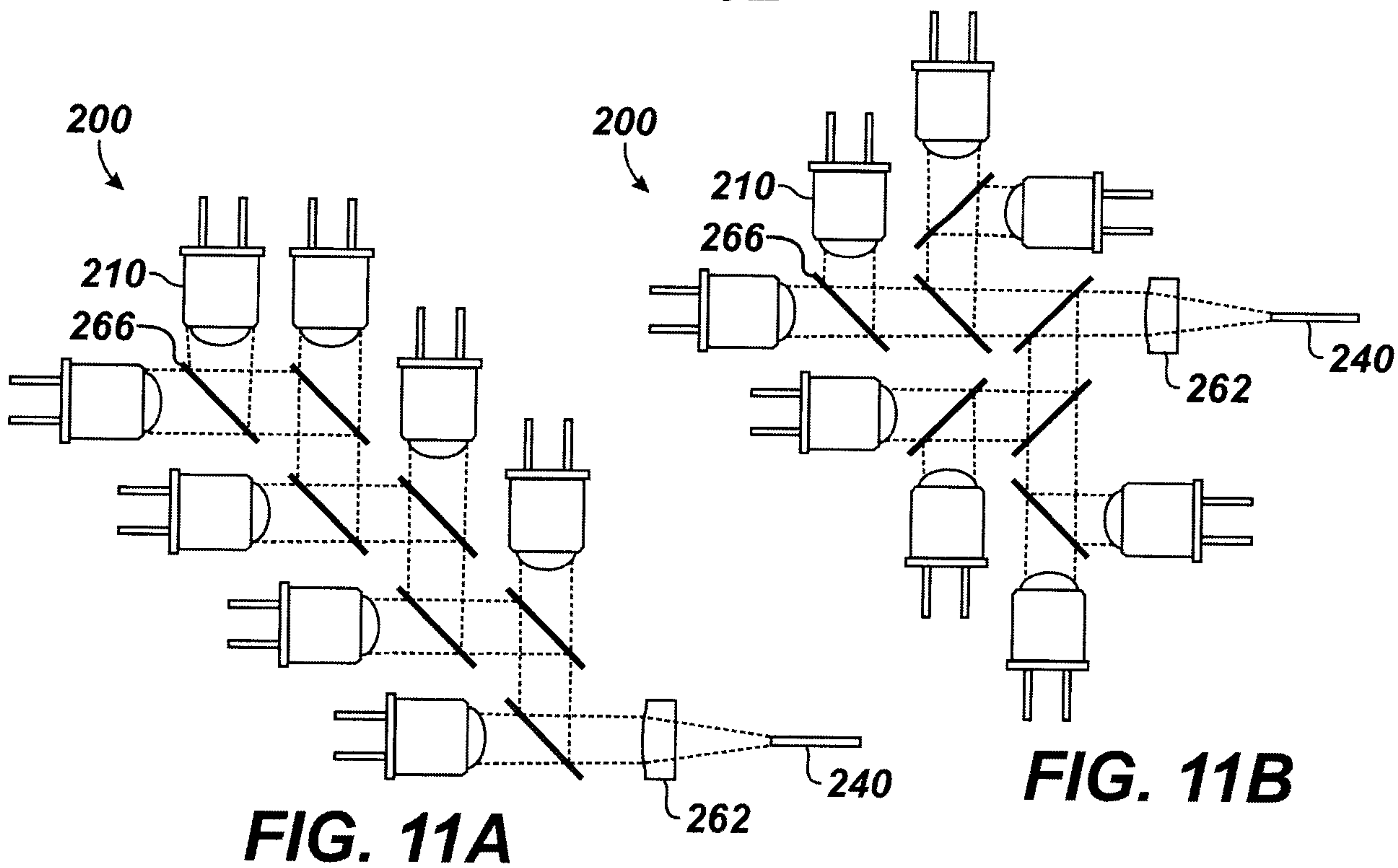
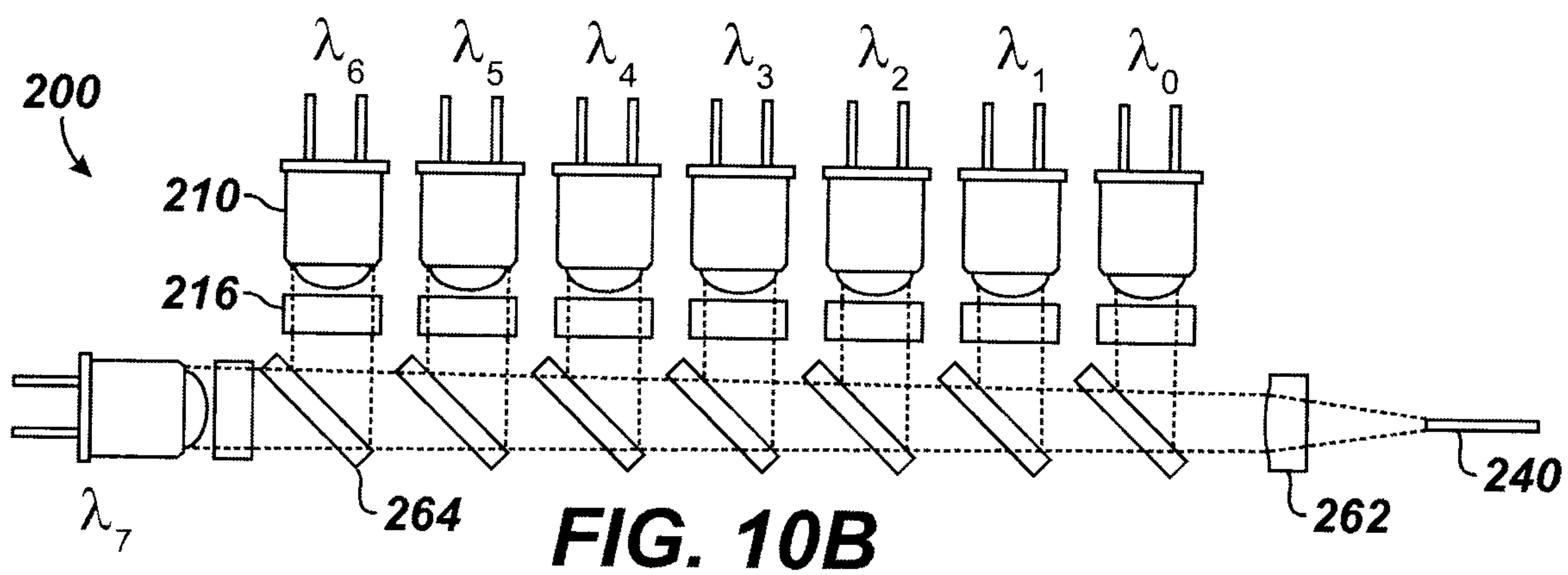
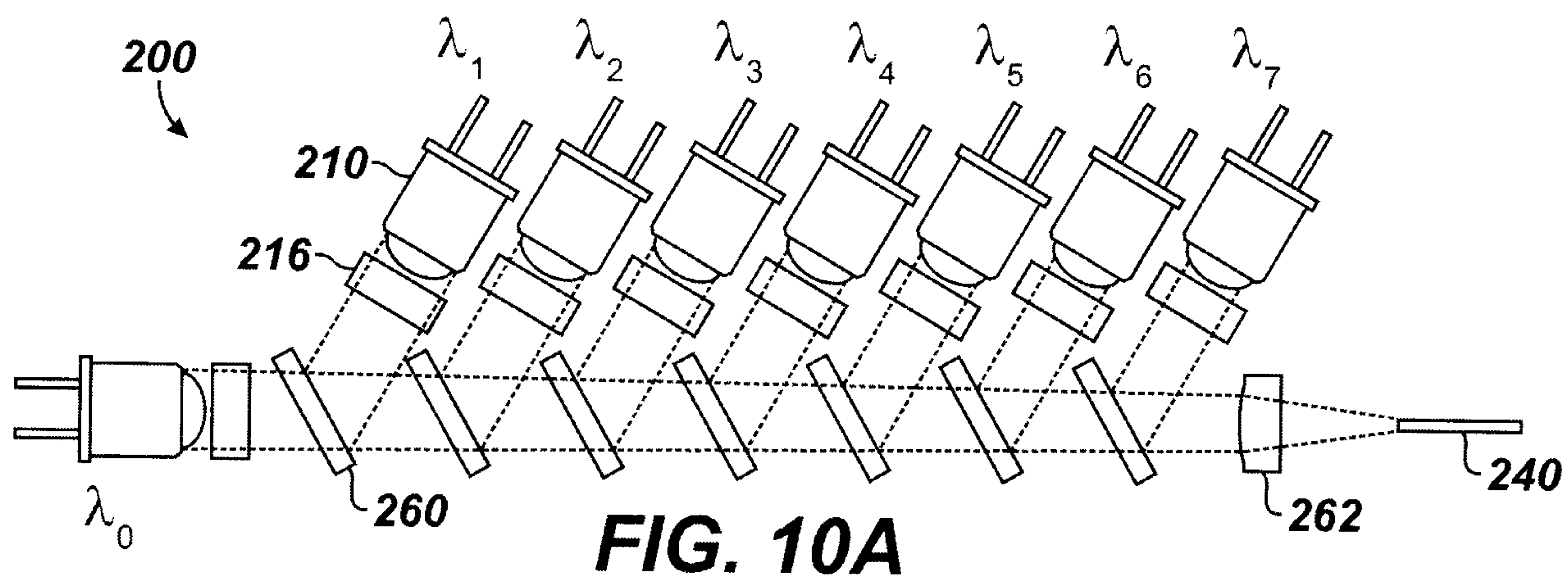
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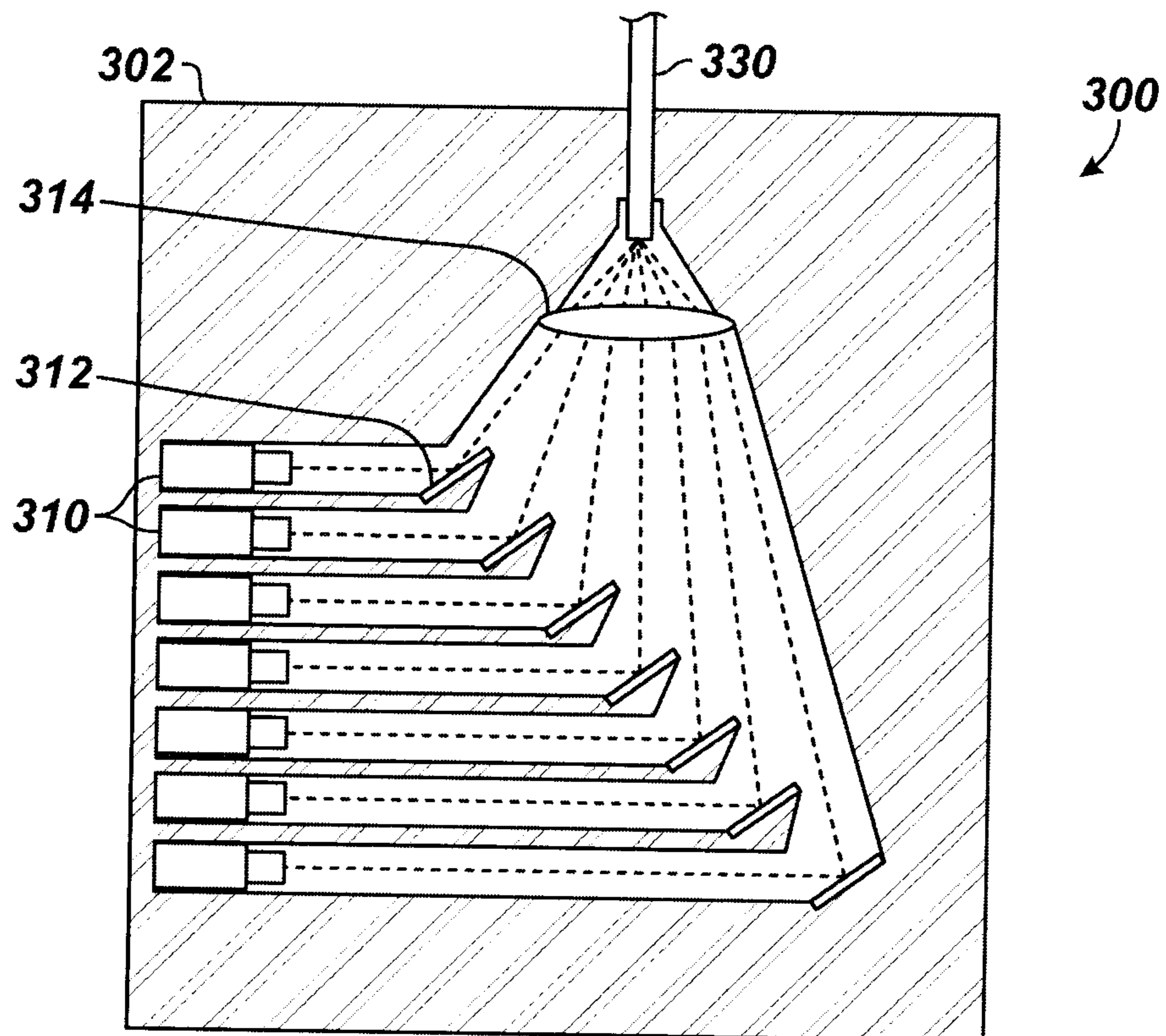
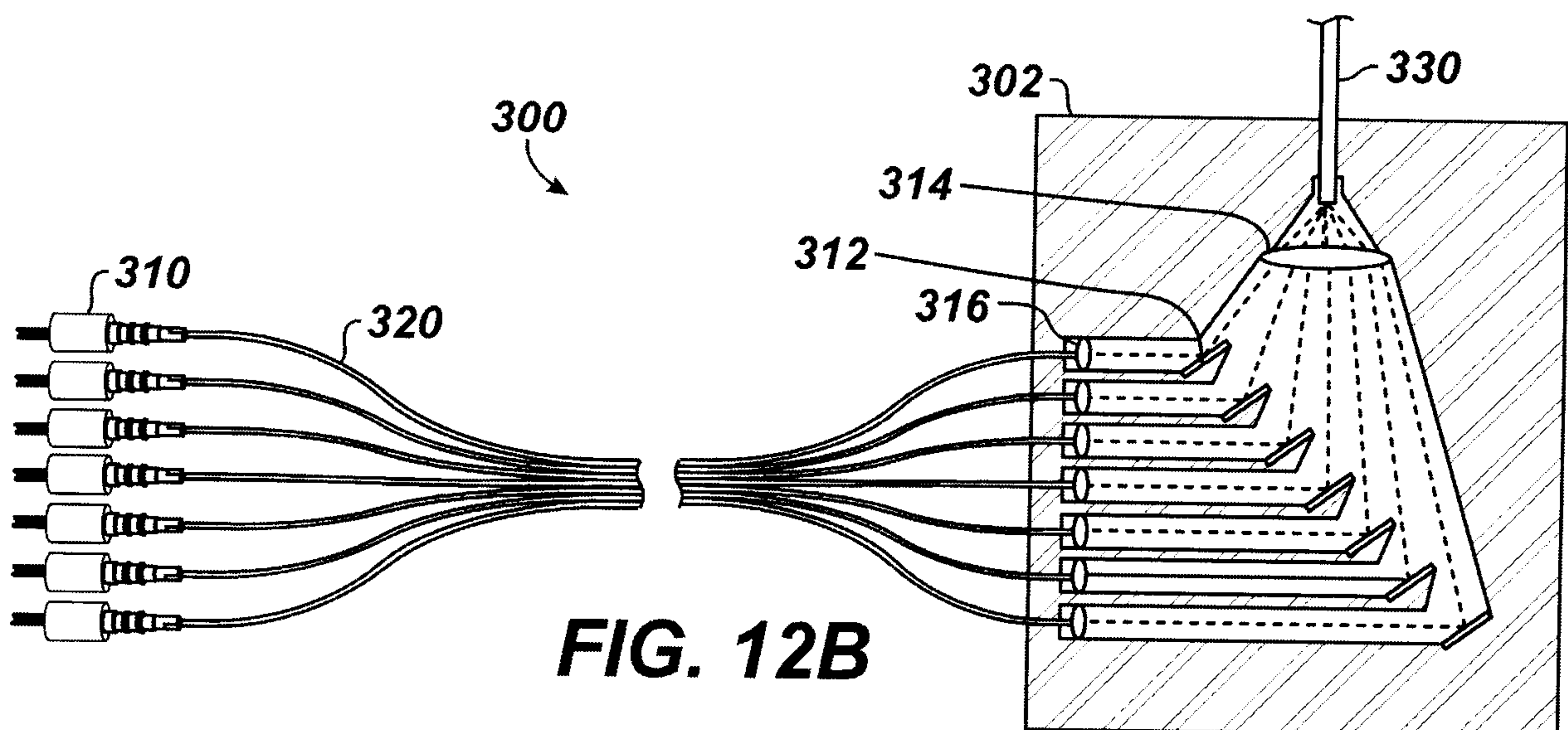
**FIG. 7****FIG. 8****FIG. 9**

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**FIG. 12A****FIG. 12B**

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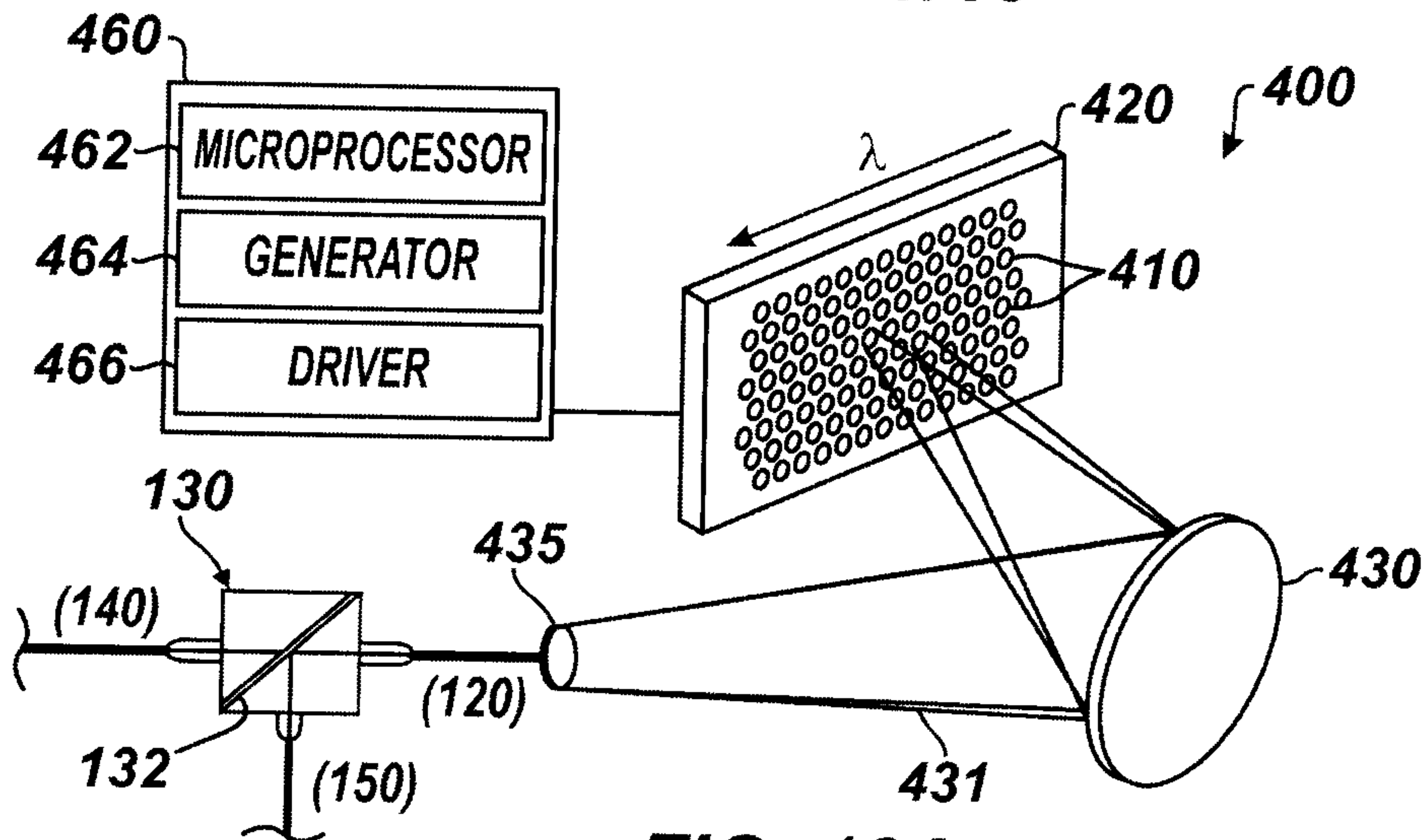


FIG. 13A

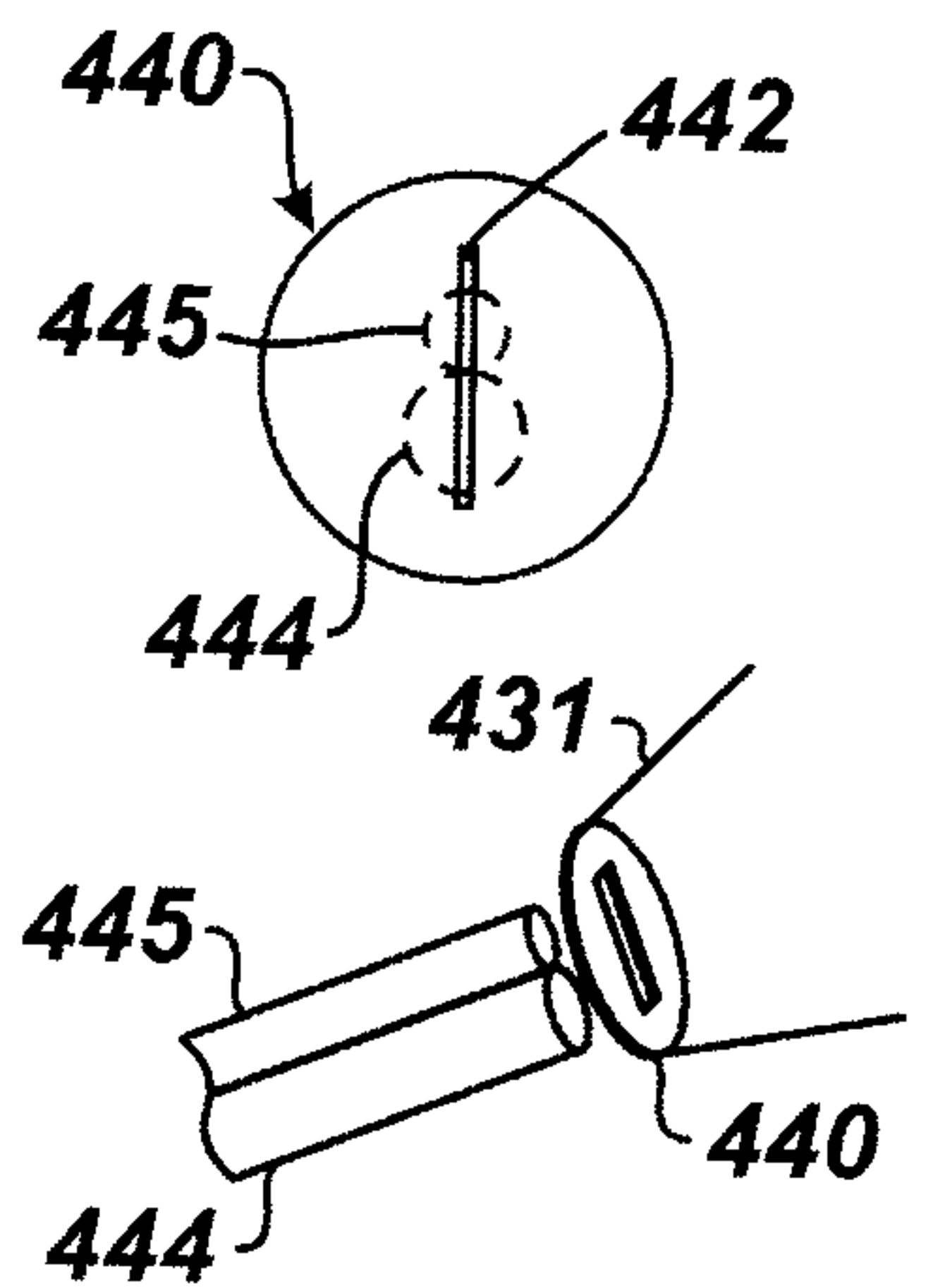


FIG. 13B

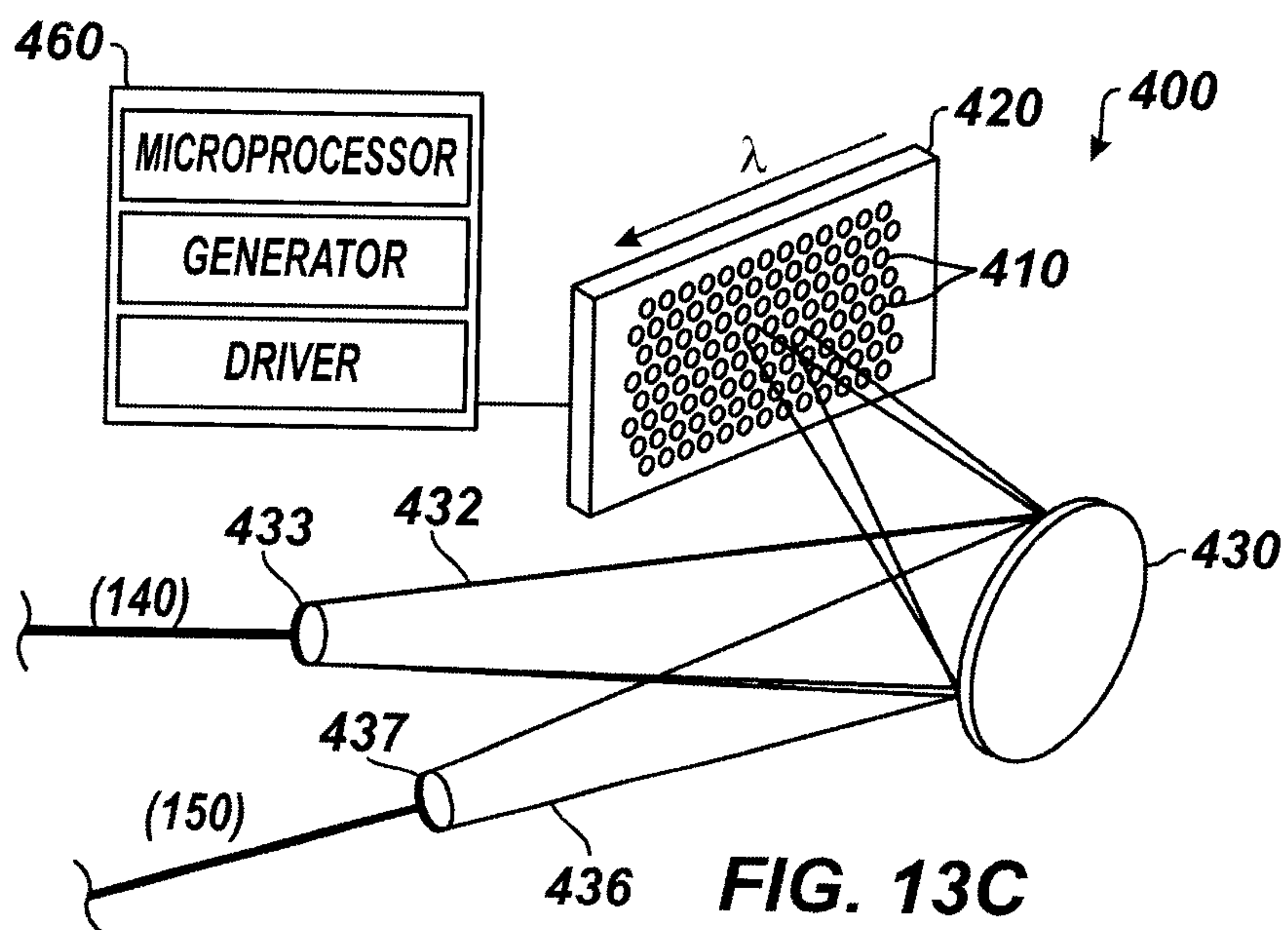


FIG. 13C

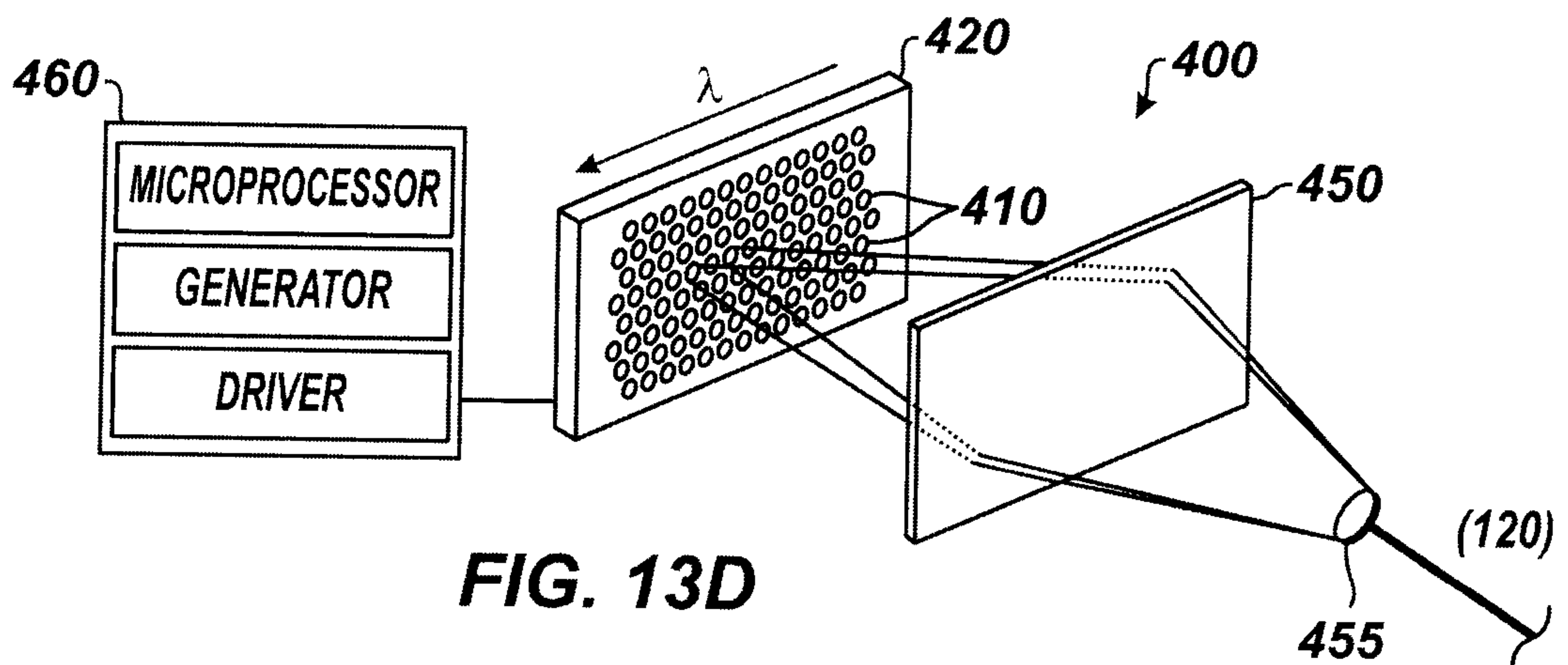
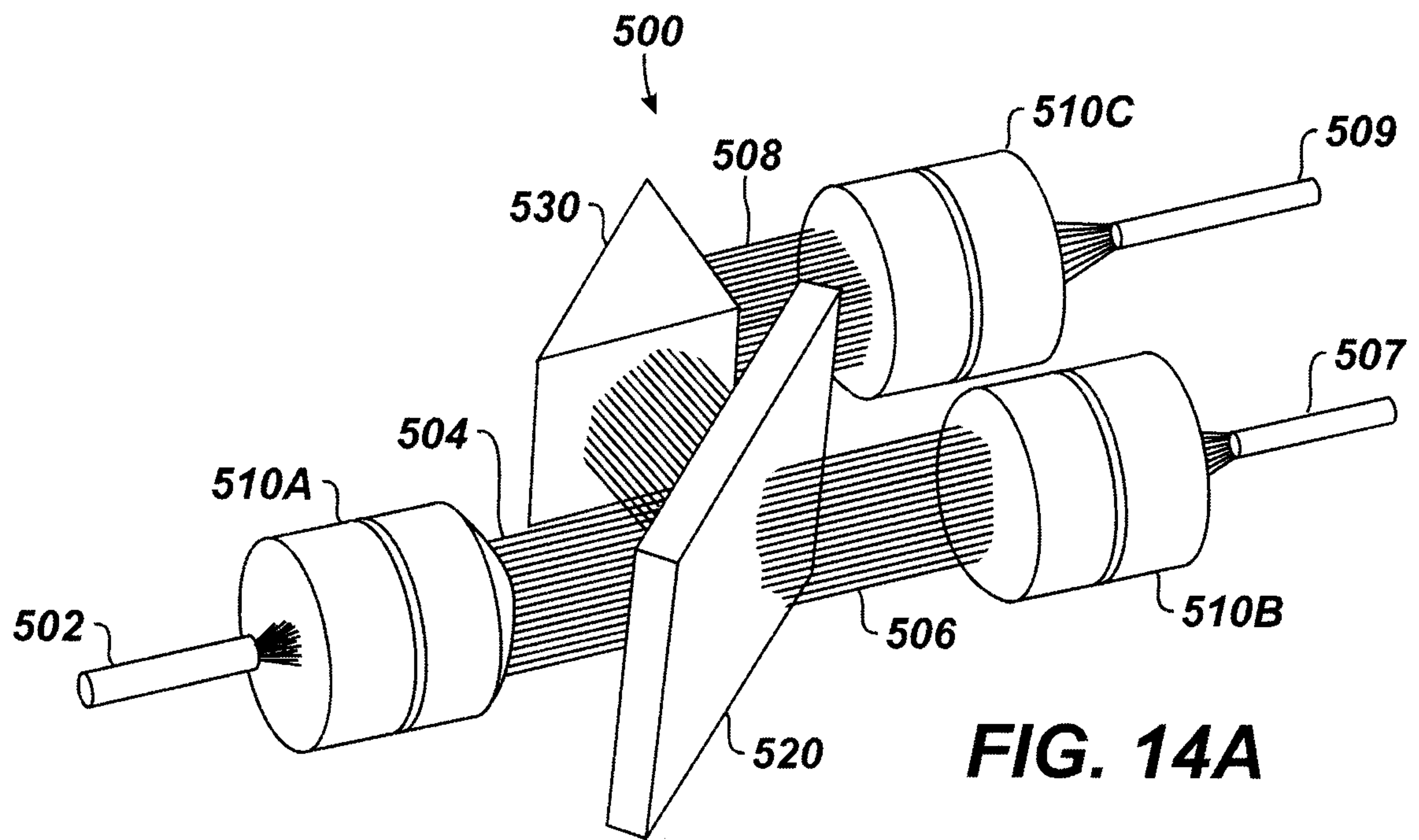
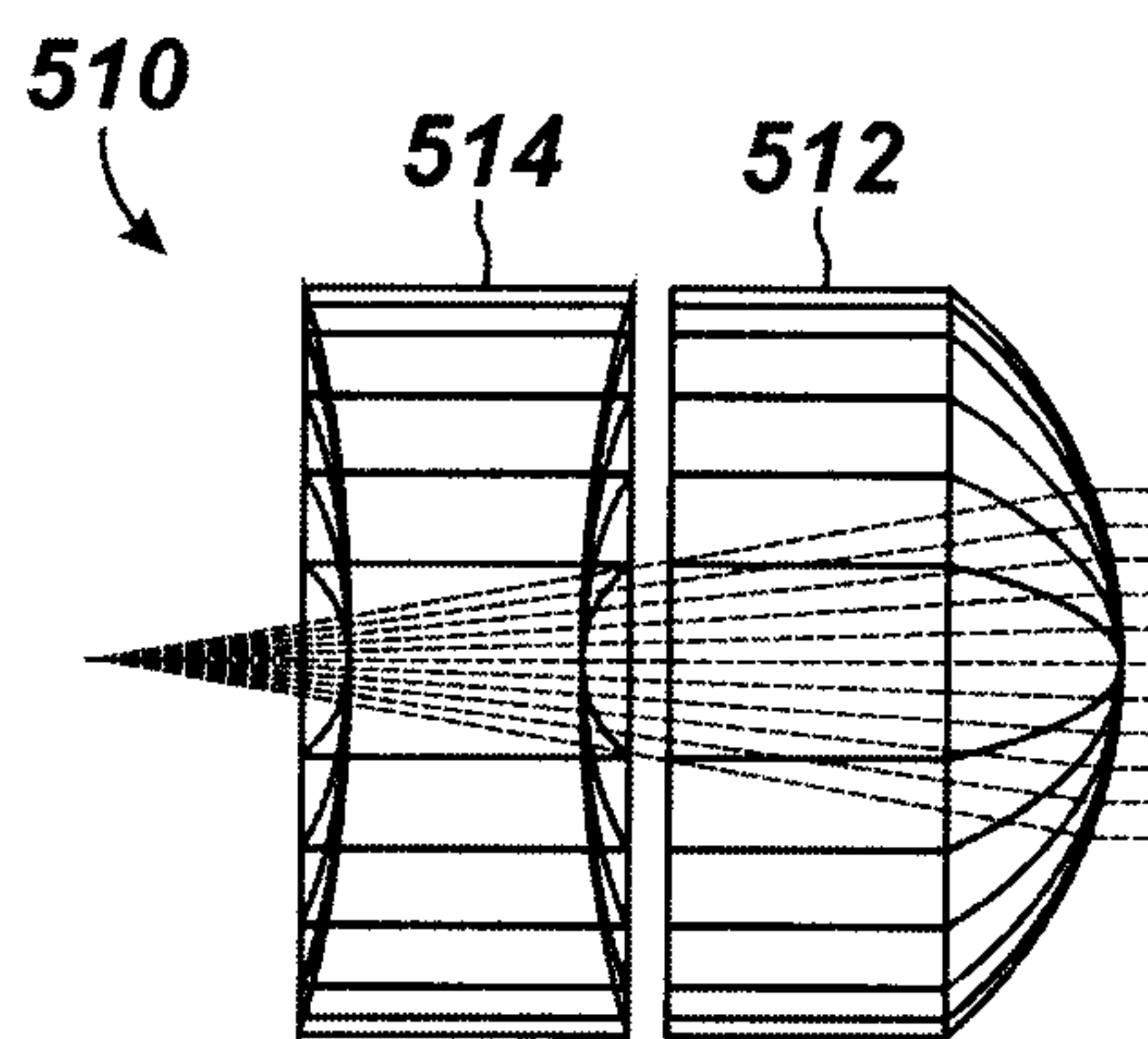


FIG. 13D

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**FIG. 14A****FIG. 14B**

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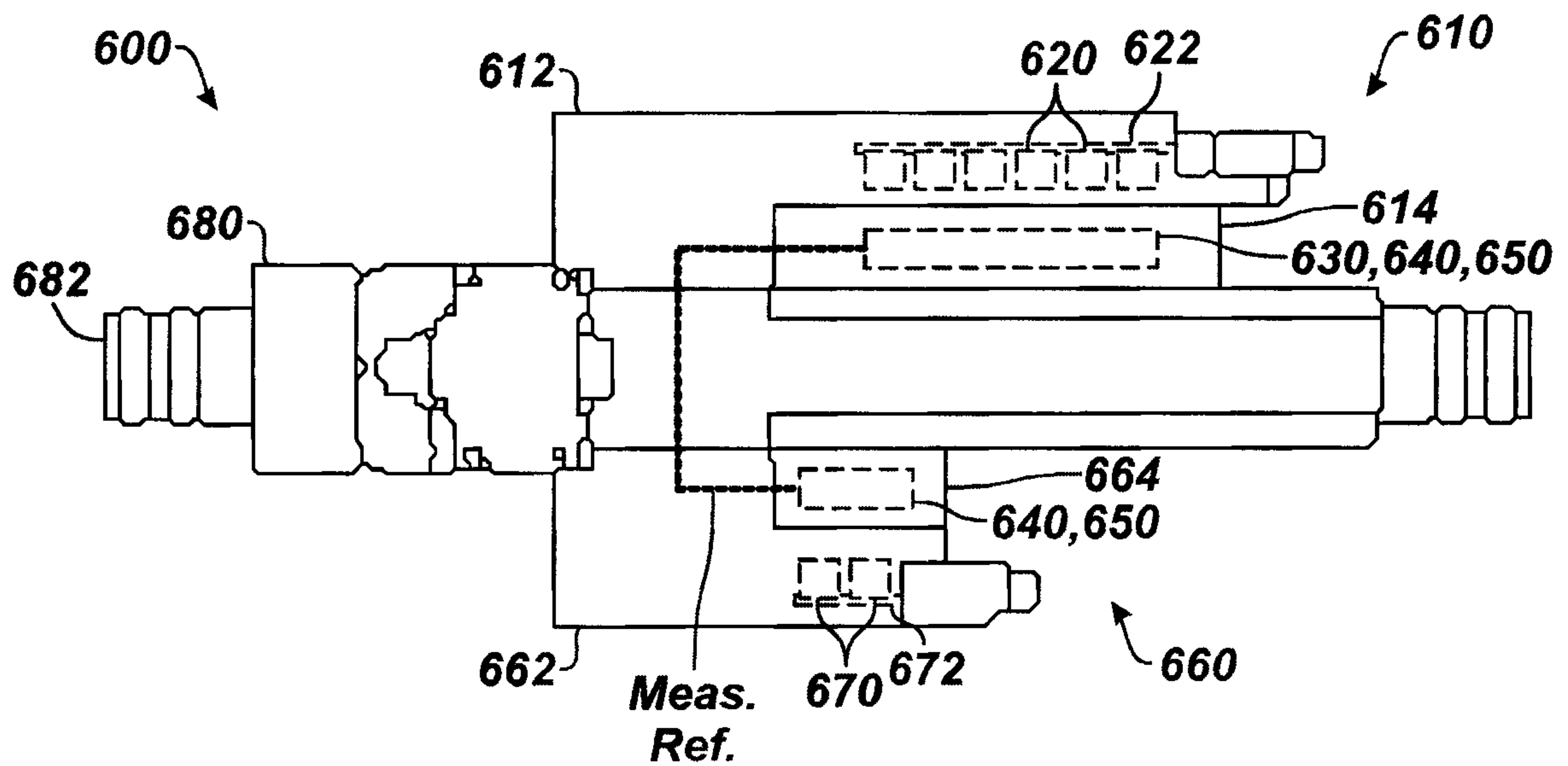


FIG. 15A

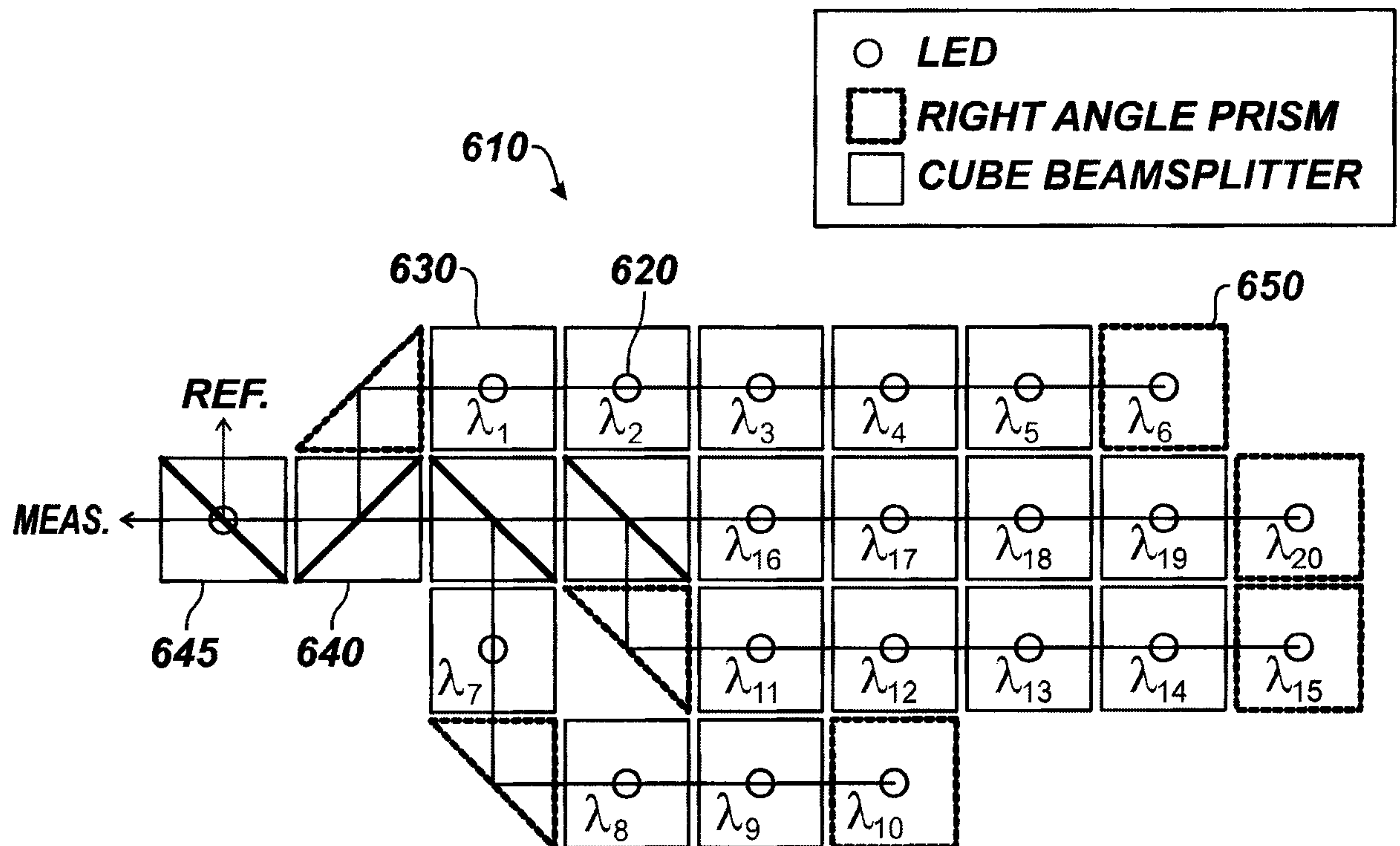
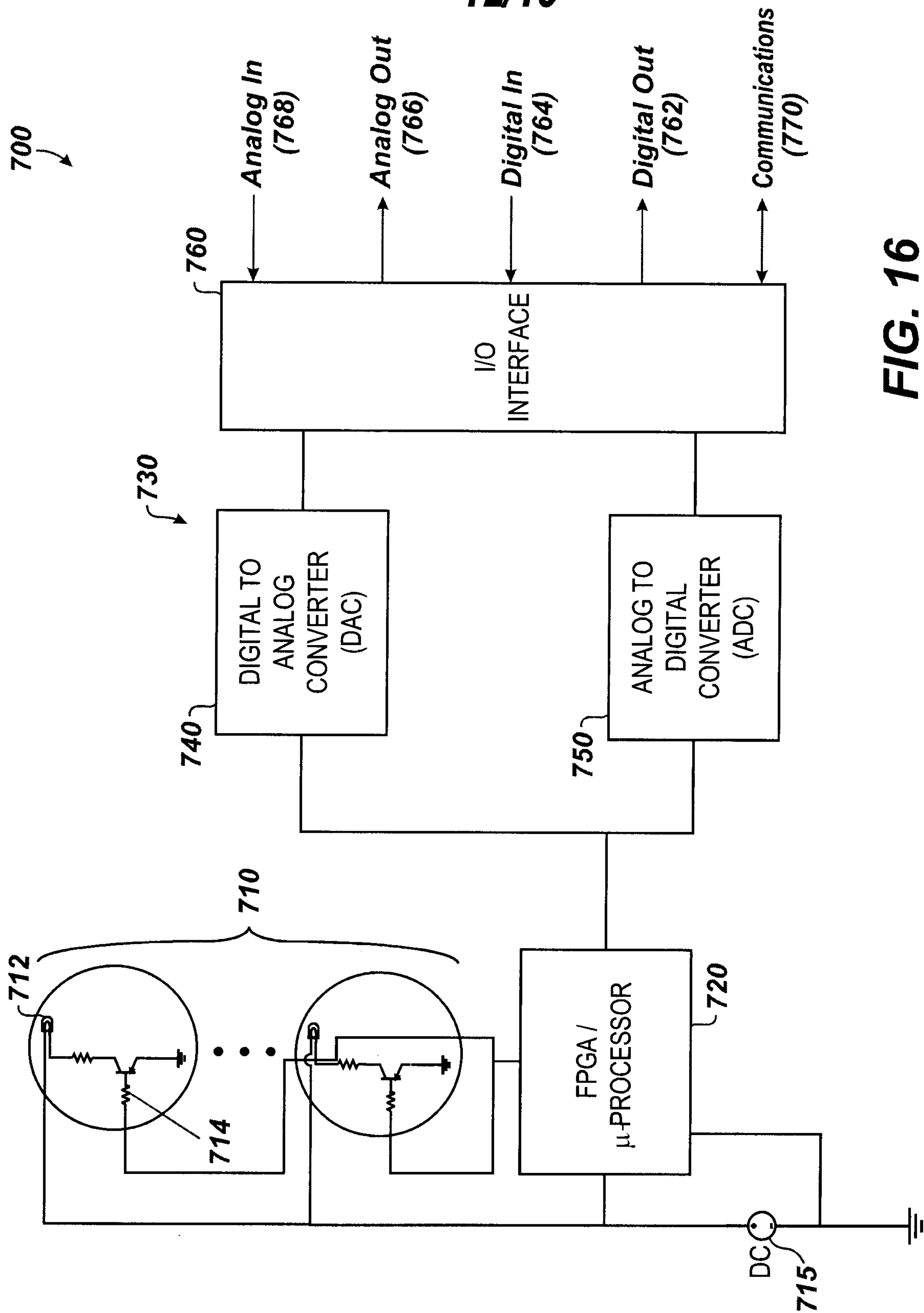


FIG. 15B

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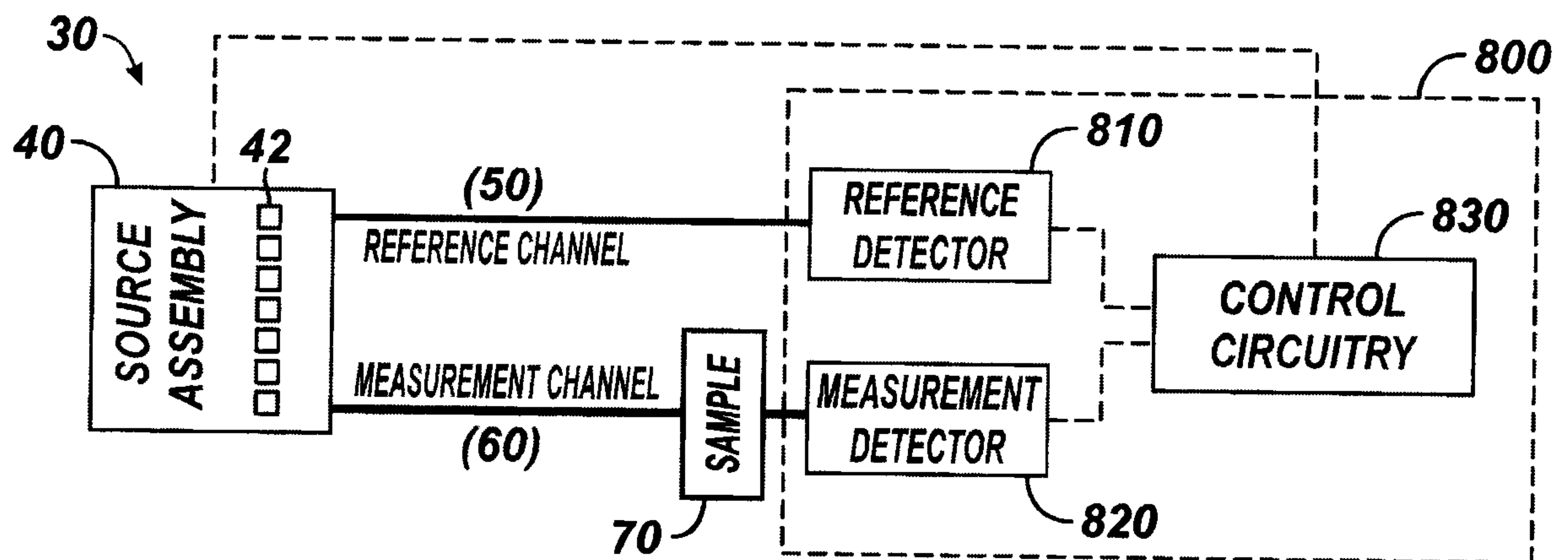


FIG. 17A

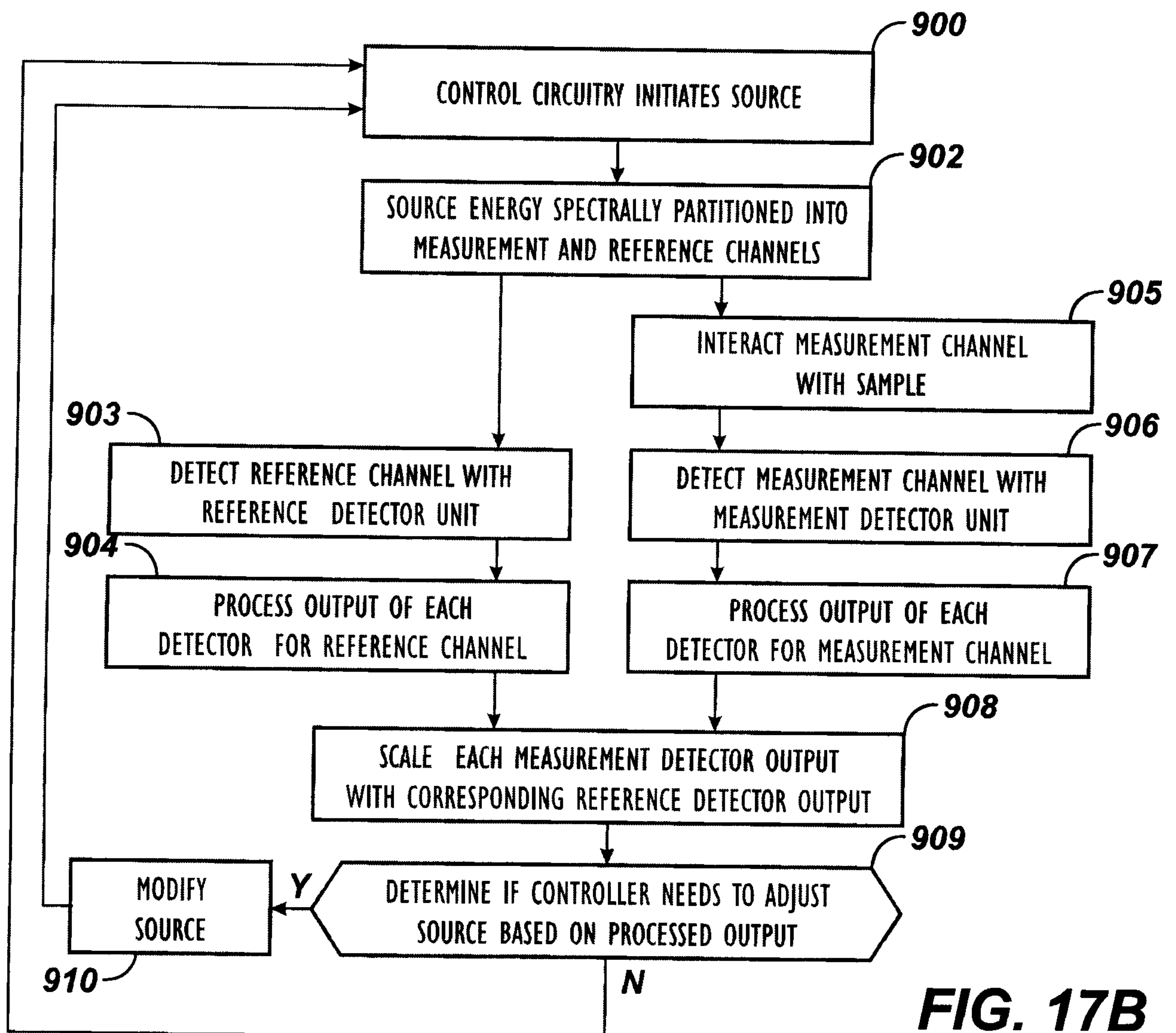
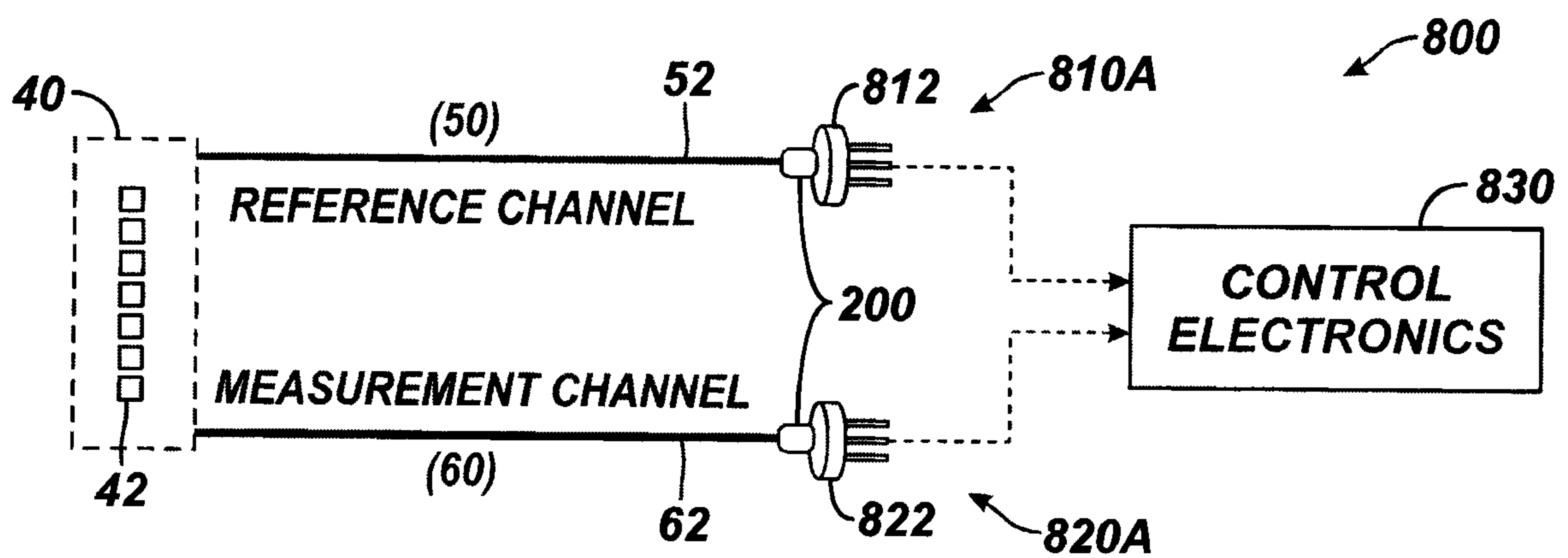
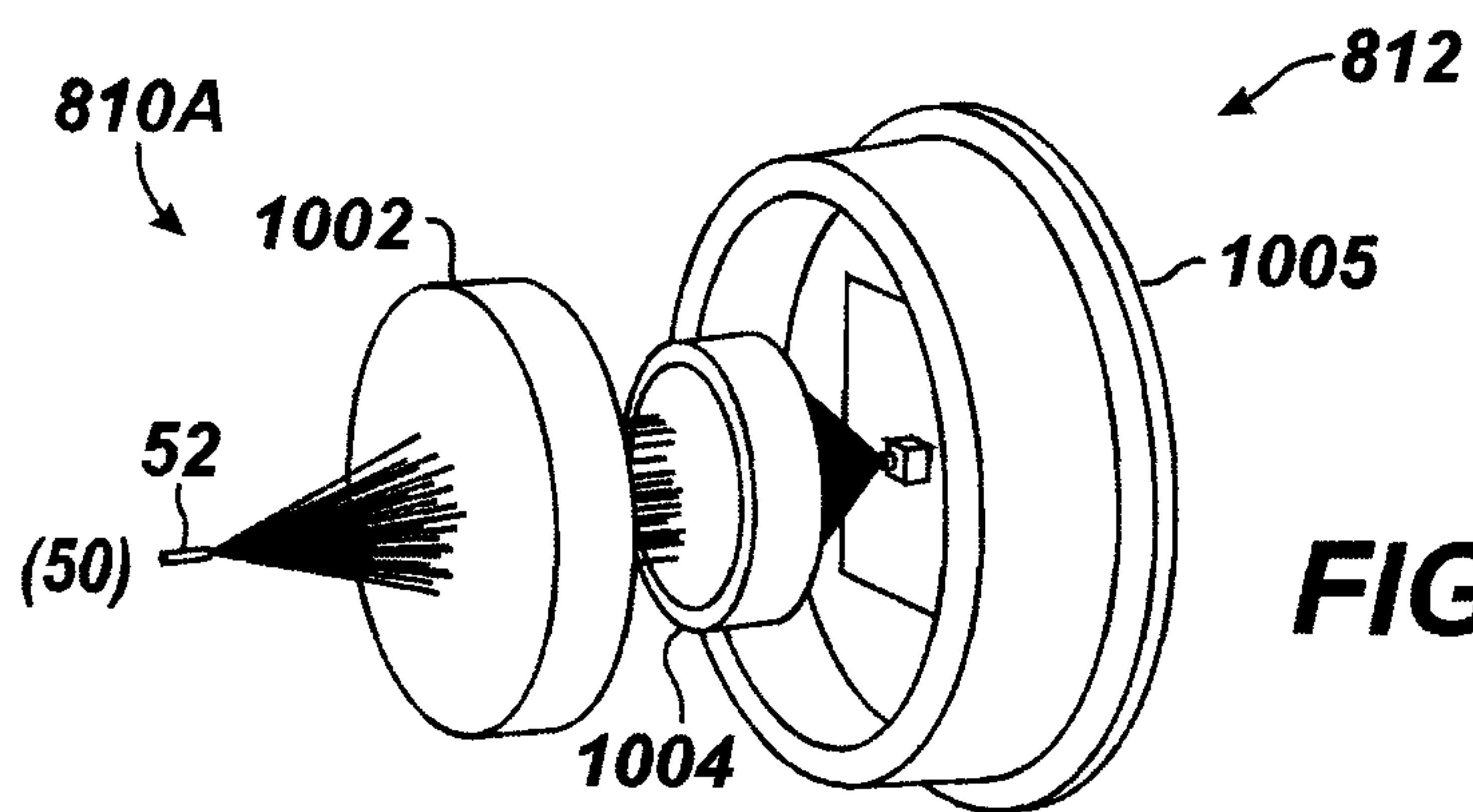
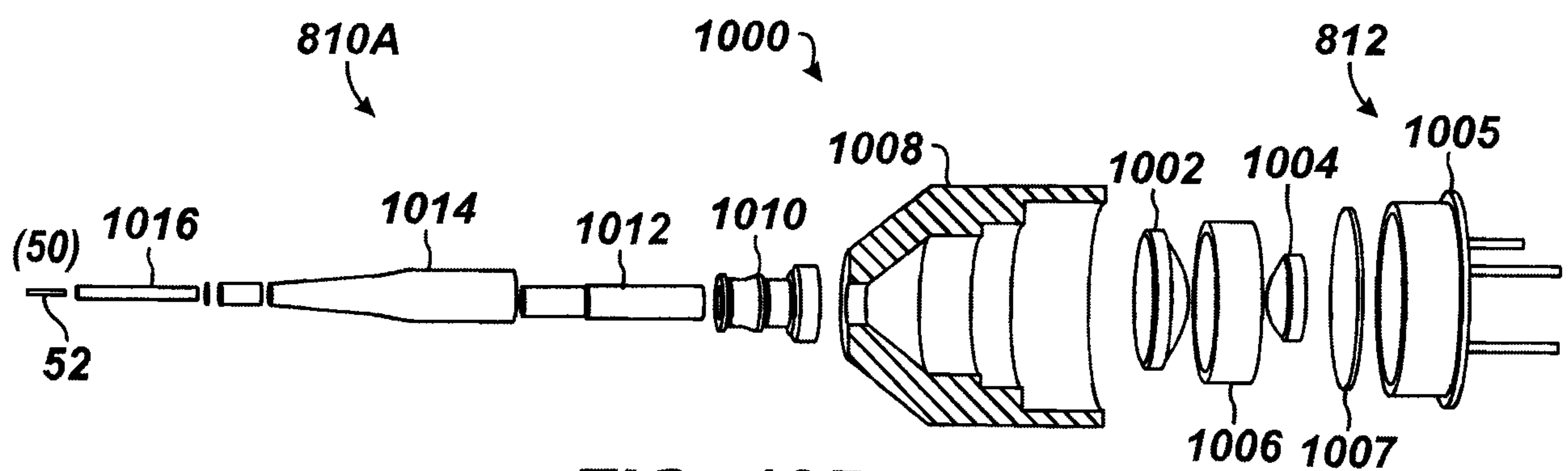


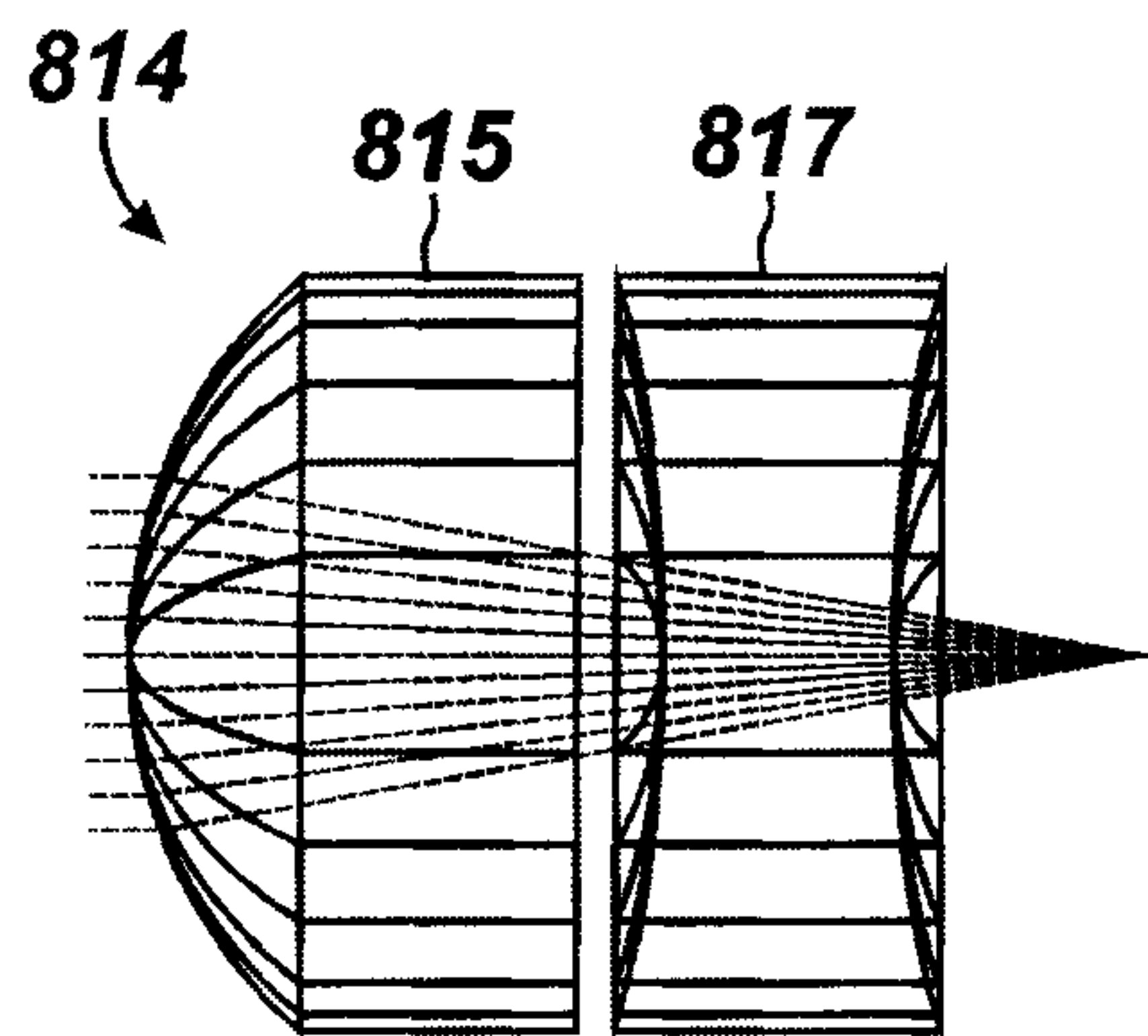
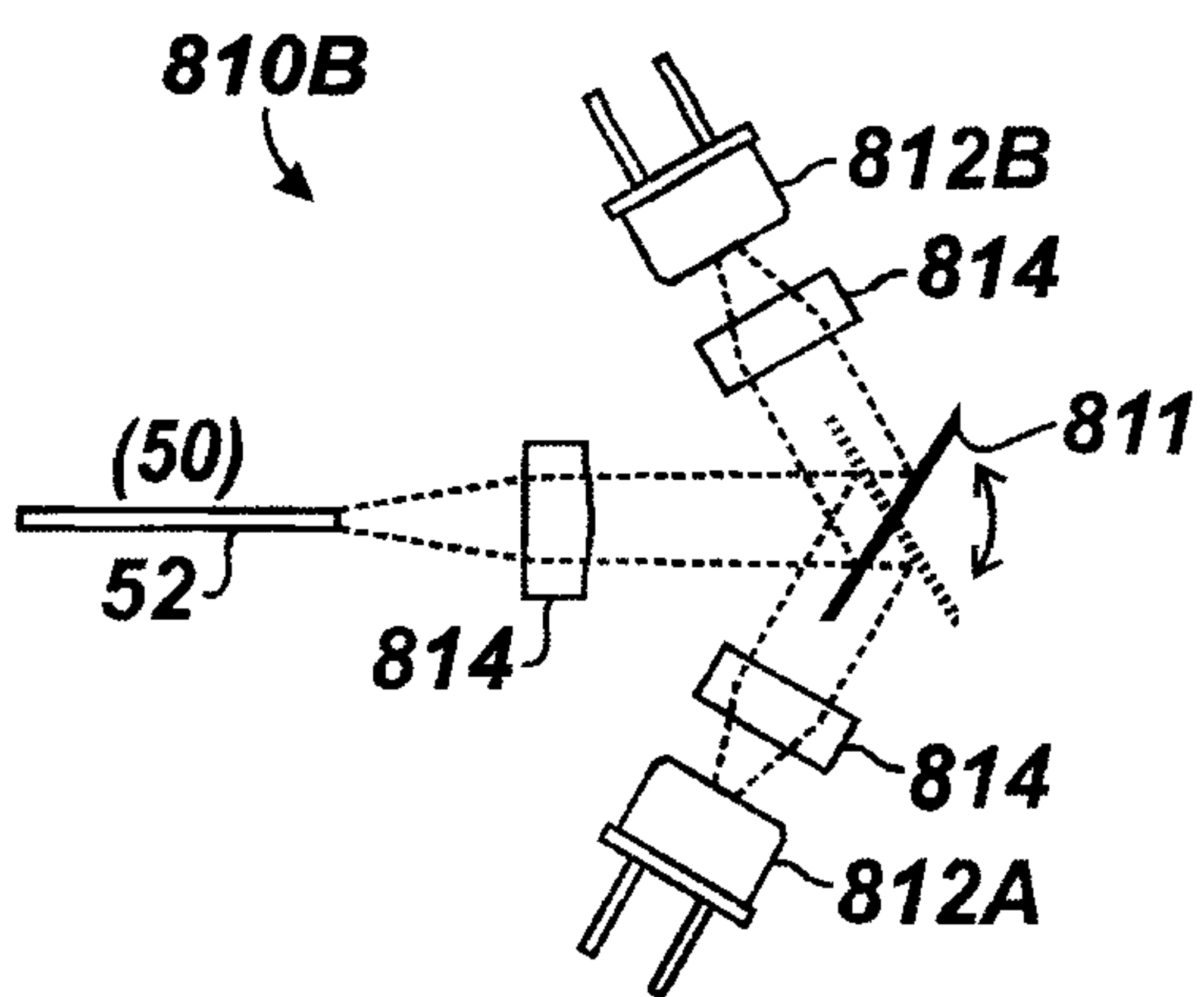
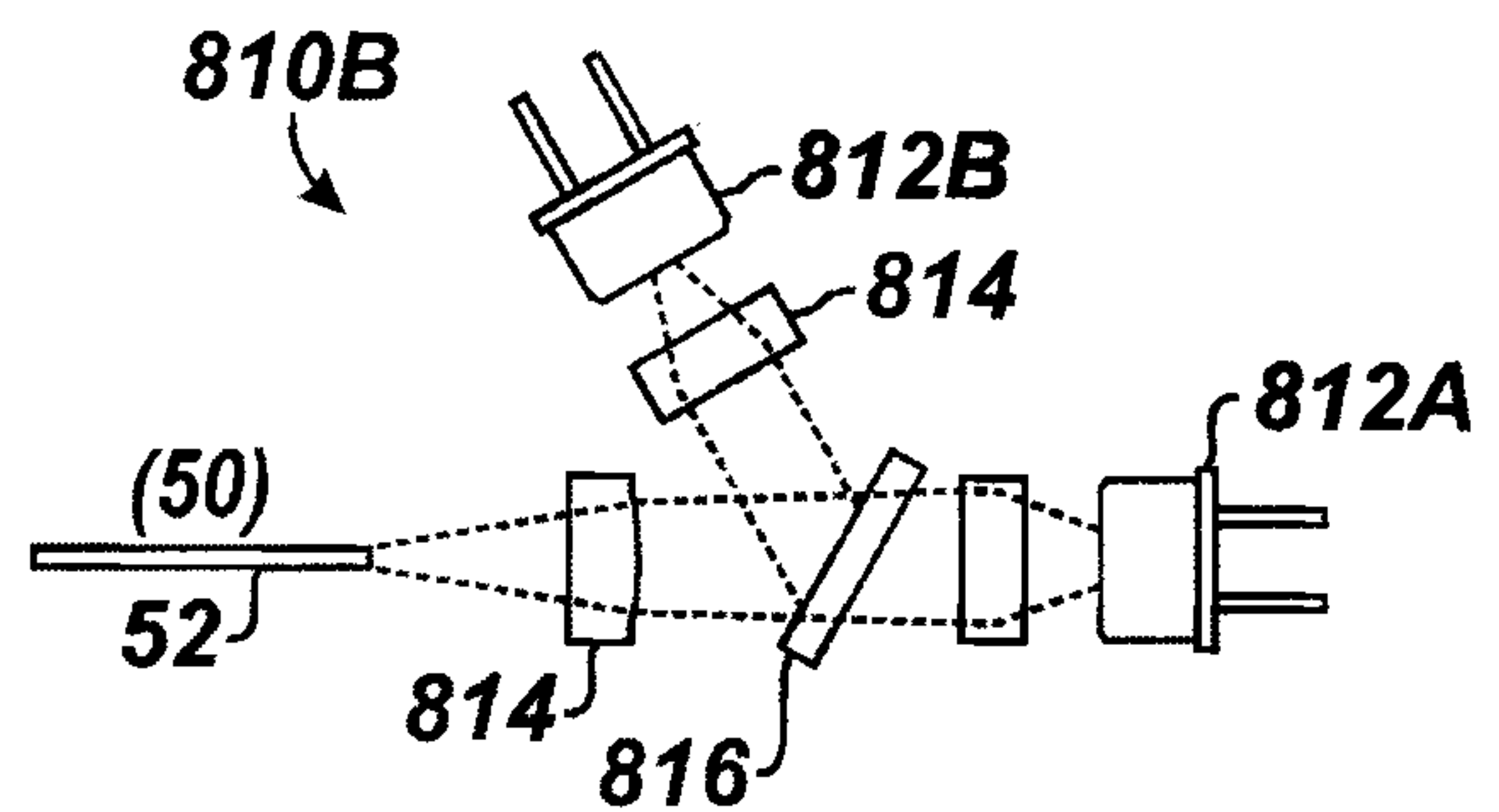
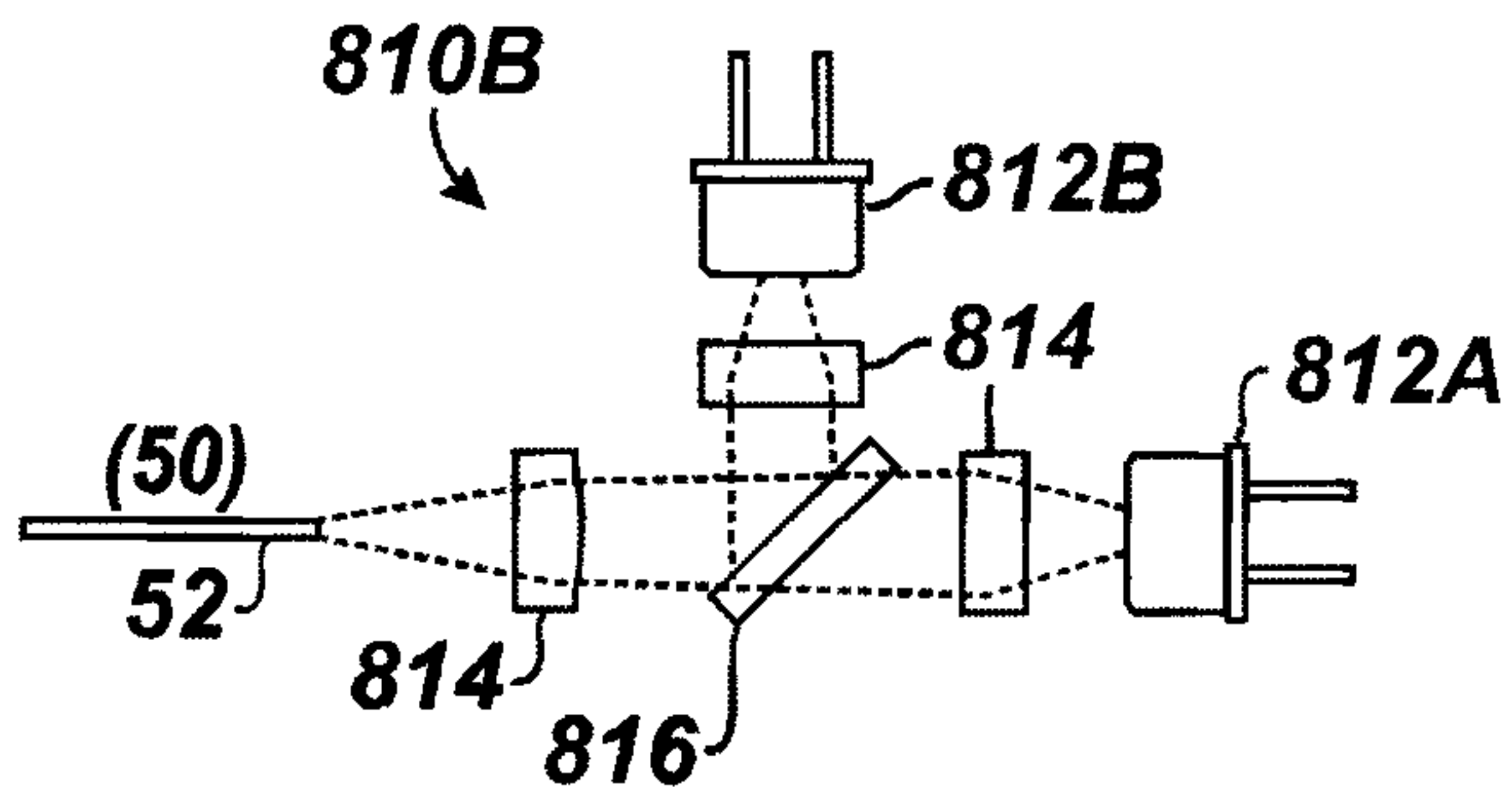
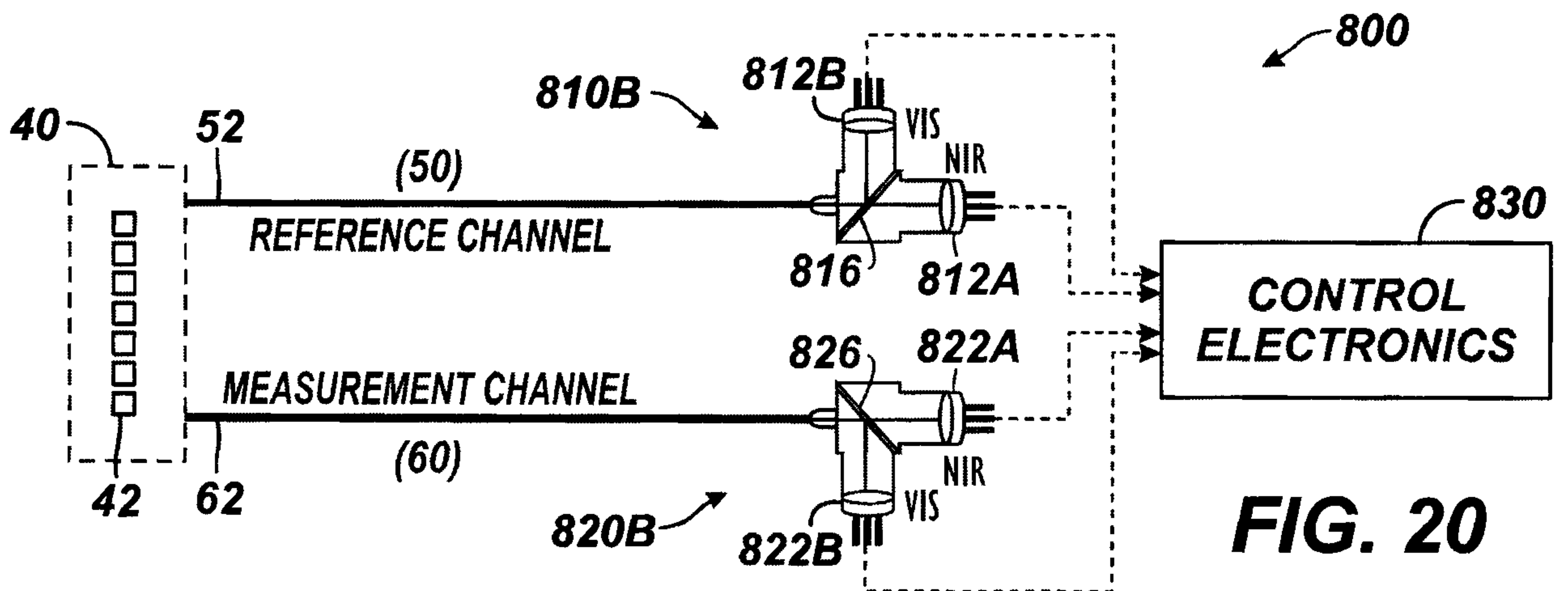
FIG. 17B

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**14/19****FIG. 18****FIG. 19A****FIG. 19B**

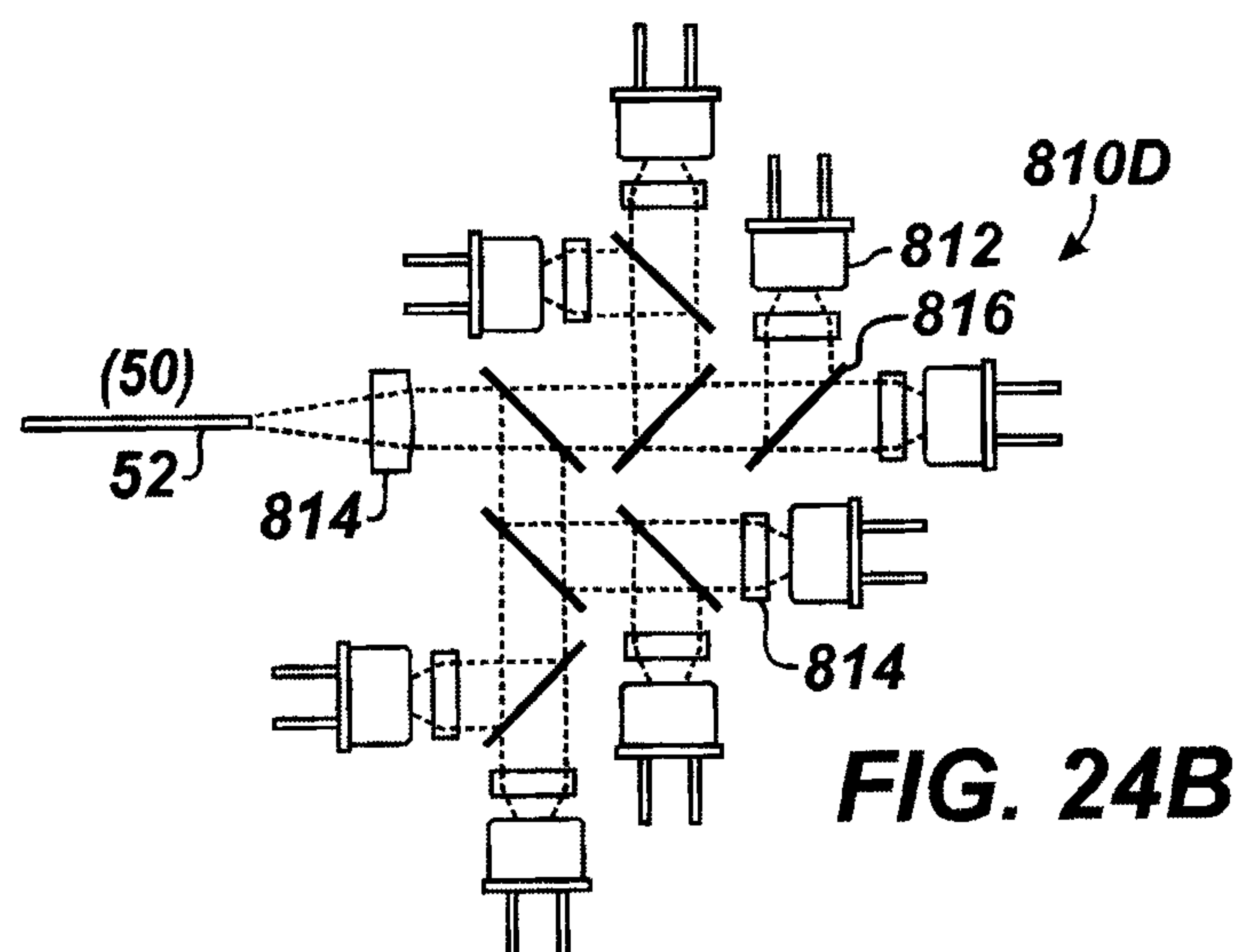
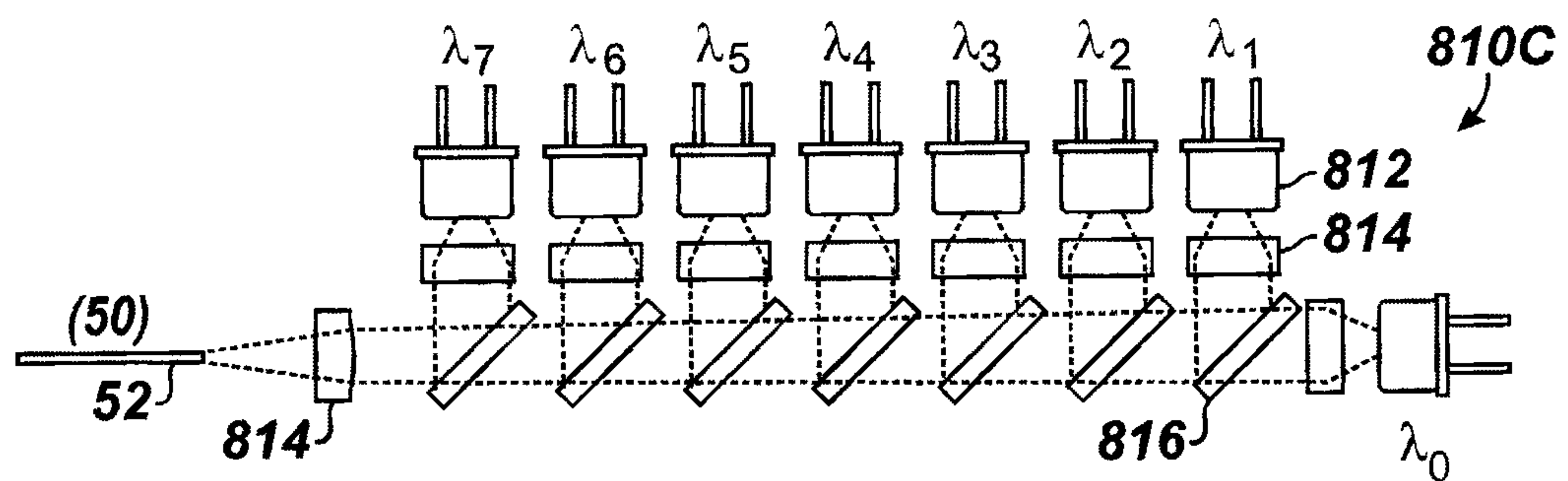
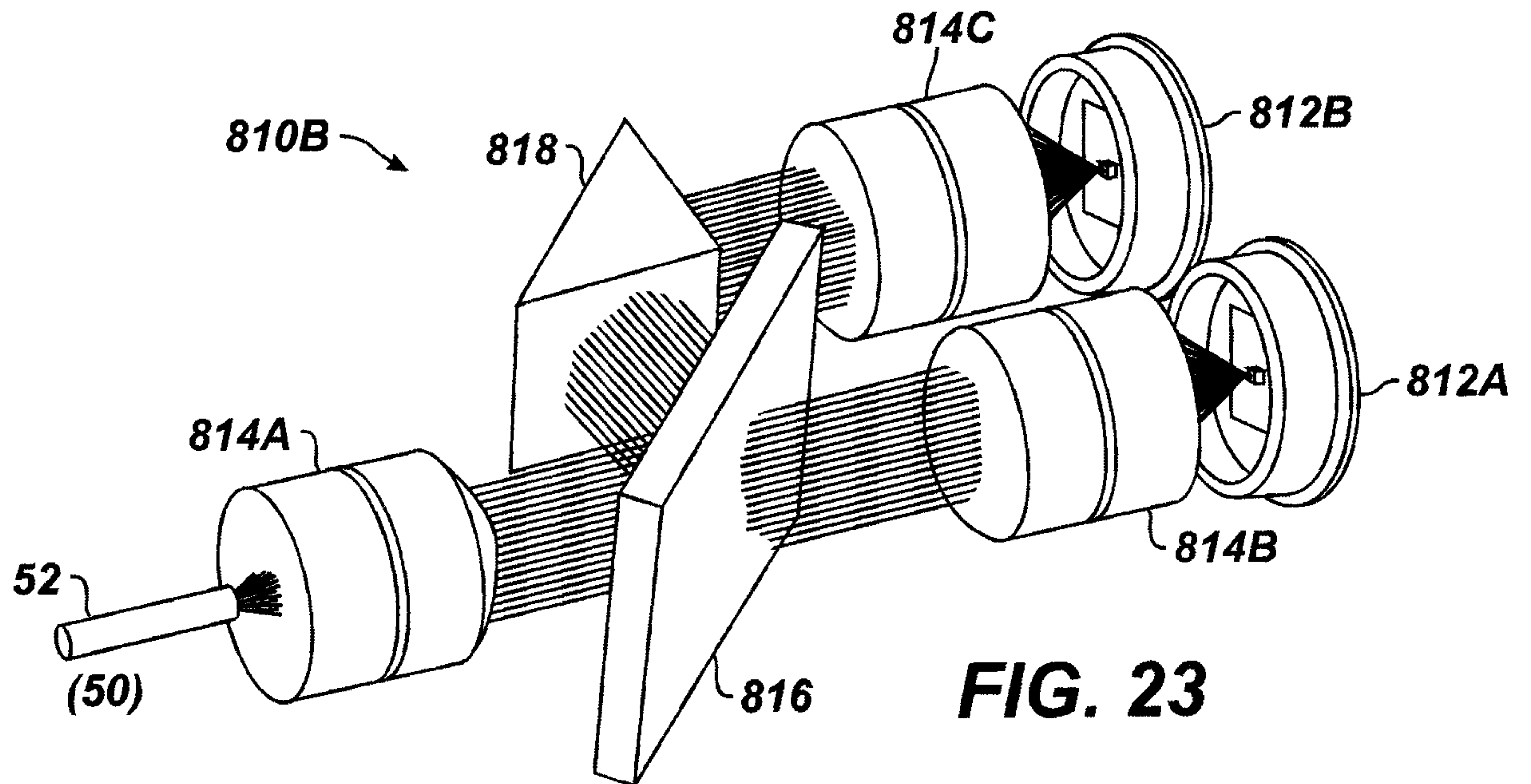
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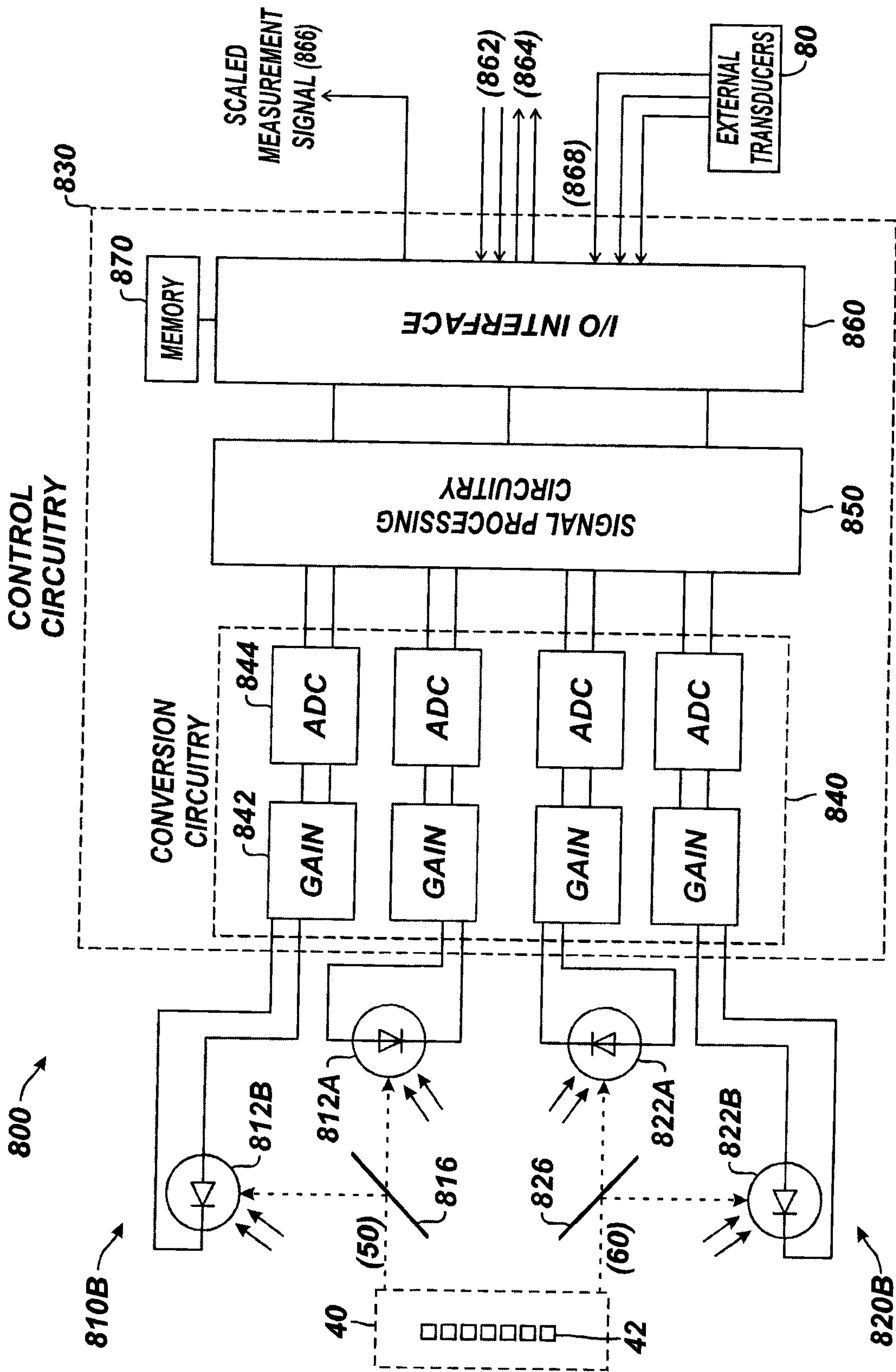


FIG. 25

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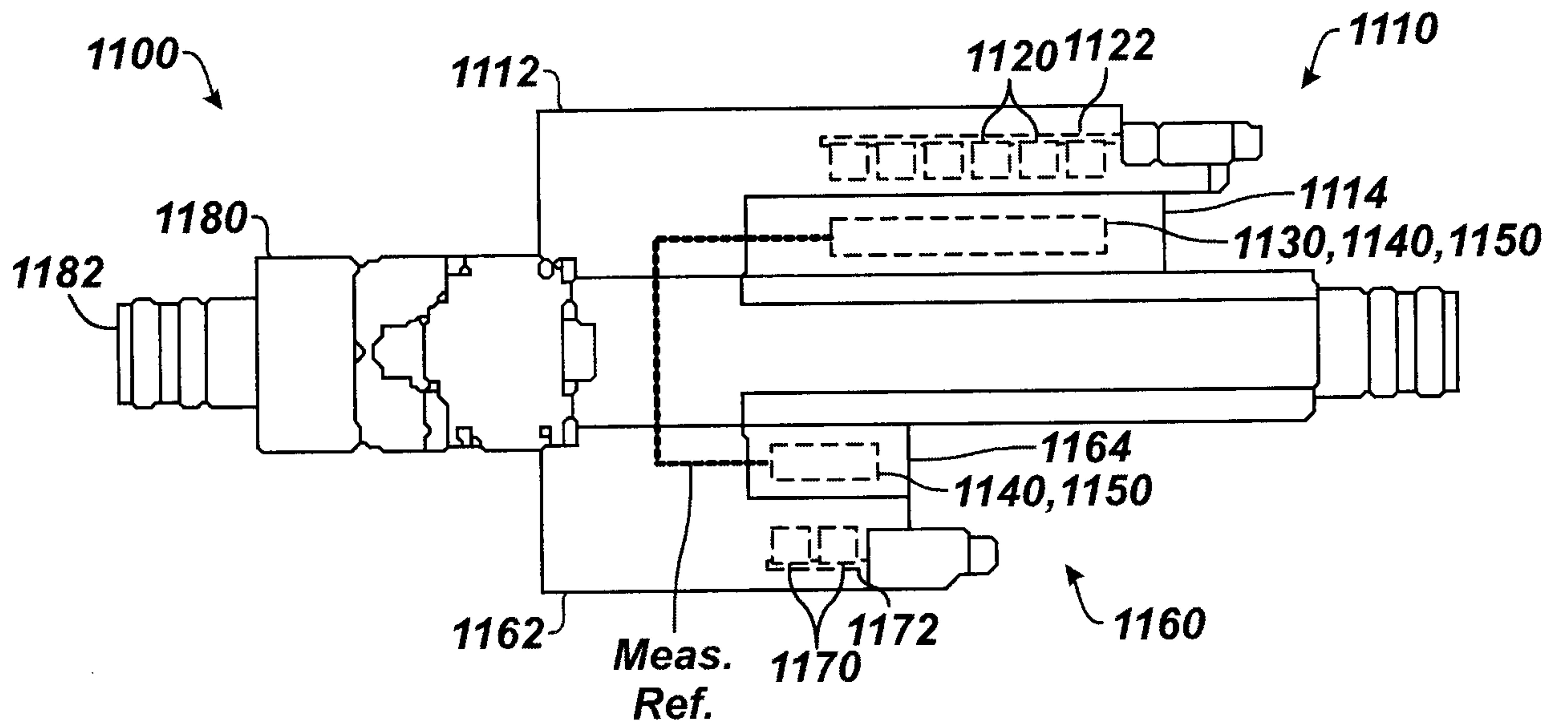


FIG. 26

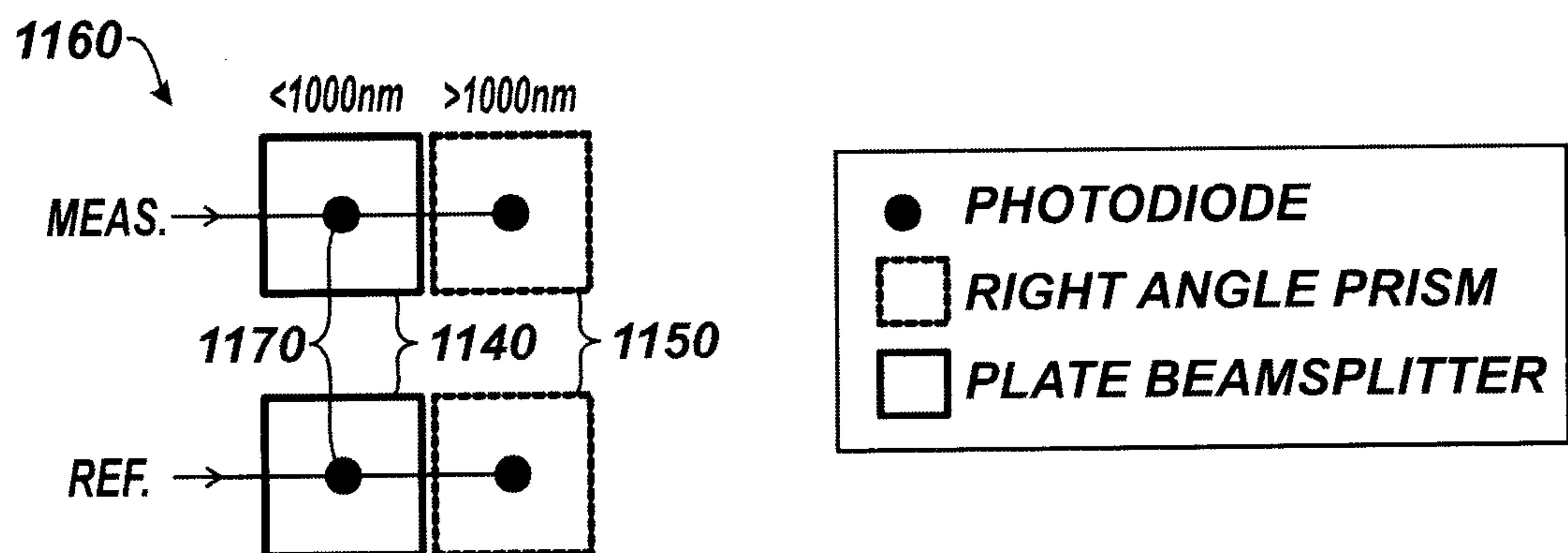
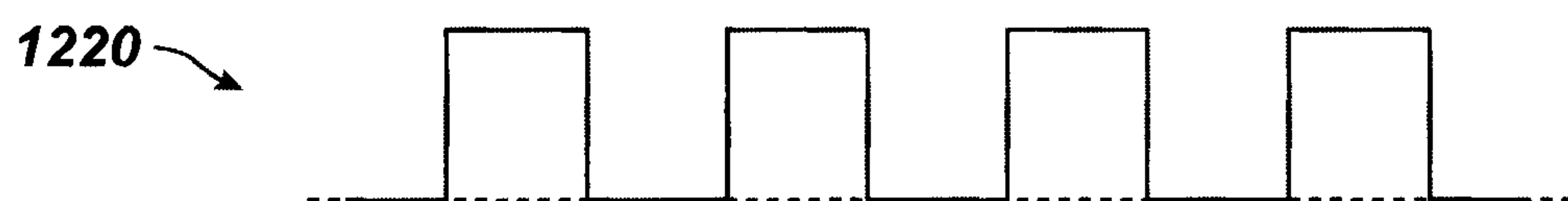
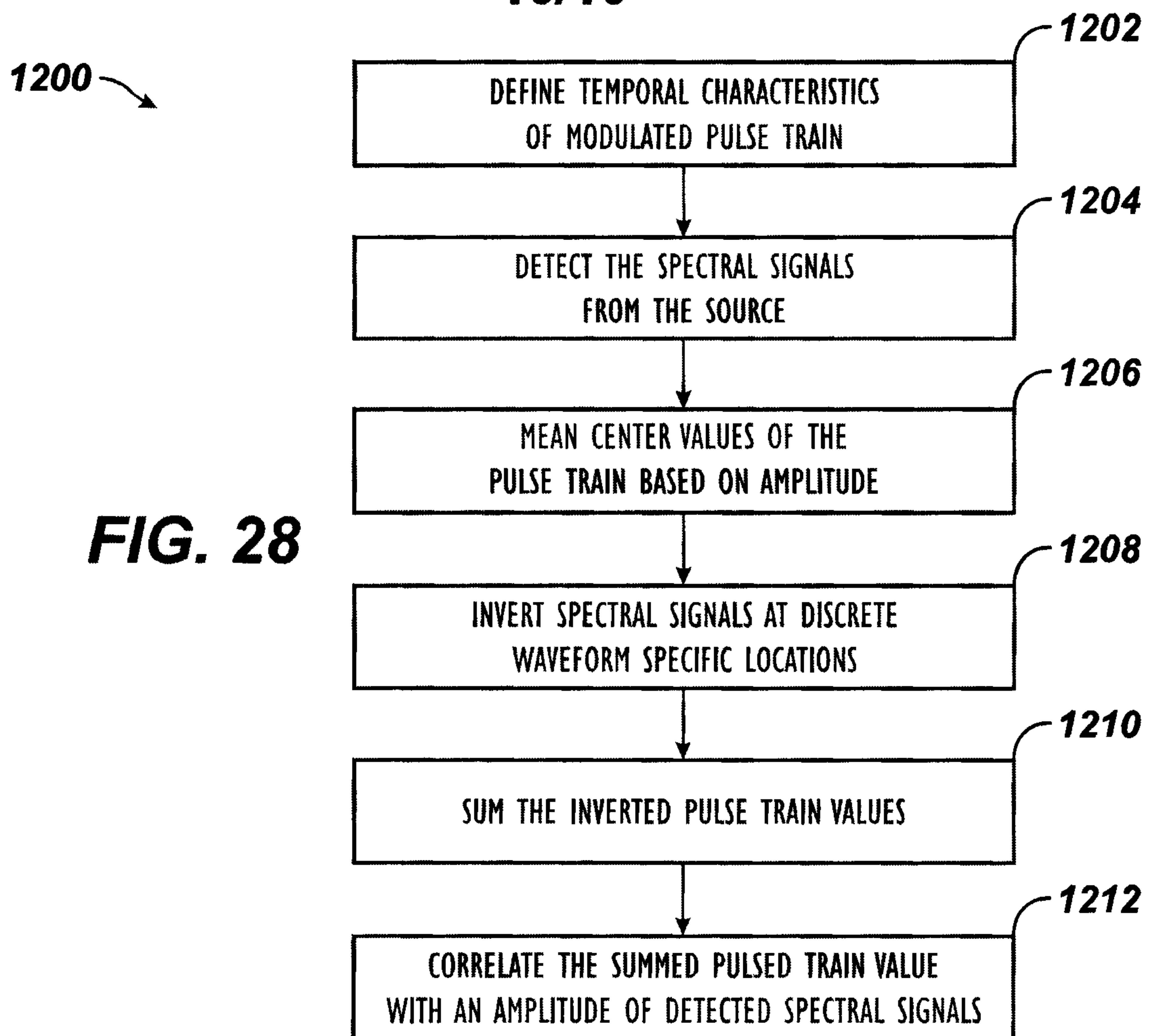
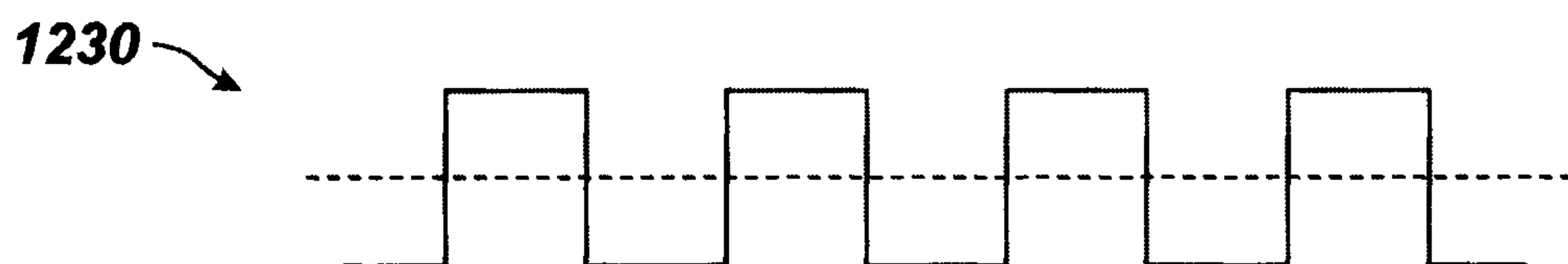
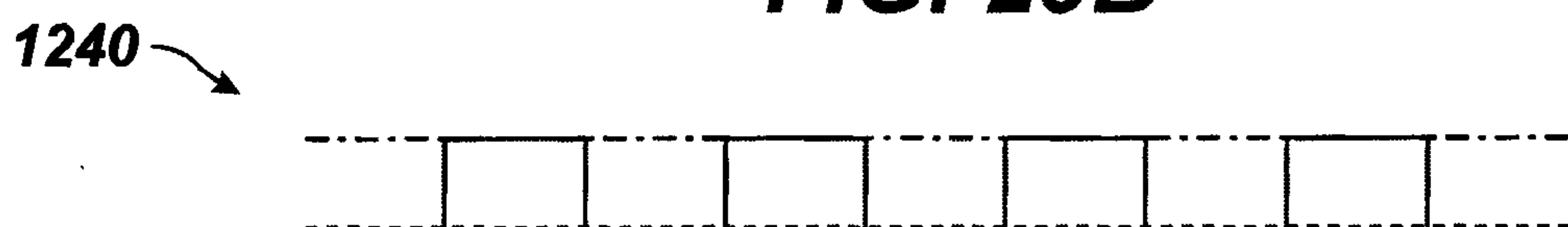


FIG. 27

**19/19****FIG. 29A****FIG. 29B****FIG. 29C**

